ELEMENTARY MANUAL

OF

MAGNETISM AND ELECTRICITY.

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MAGNETISM AND ELECTRICITY.

SPECIALLY ARRANGED FOR THE USE OF FIRST-YEAR SCIENCE AND ART DEPARTMENT AND OTHER ELECTRICAL STUDENTS.

BY

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"ELECTRICAL RULES," AND TEXT-BOOKS ON "STEAM AND STEAM-ENGINES," ETC.

SECOND EDITION.

With Numerous Illustrated Experiments and Examination-Questions.

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PREFACE.

THIS Manual has been written expressly for Elementary or First-year Students of Magnetism and Electricity. It covers the Elementary Stage of the Science and Art Department's Examination; but, at the same time, the treatment is sufficiently general for students of Public and Private Schools who have not these examinations specially in view.

The book is divided into three distinct parts. Part I. treats of *Magnetism;* Part II. of Electro-Magnetism and Current Electricity under the general heading of *Voltaic Electricity;* and Part III. of *Electro-Statics*, or what is commonly termed *Frictional Electricity*. Each of these parts is sub-divided into seven or eight short Lectures, full of illustrations of apparatus and experiments.

A Test-question with Answer has been given at the end of most of the Lectures; and, in addition, a series of carefully selected questions has been arranged in the precise order of, and relating solely to, each Lecture, so that teachers and students may have a minimum of trouble in finding suitable examples. Full advantage has been taken of the excellent and searching questions set annually by the Science and Art Department's Examiners in

this subject; in fact, all those given in their Elementary examinations for the last eight years have been incorporated, together with others.

At the end of each part will be found a short Appendix on the making of Experimental Apparatus by students, and on their conducting experiments with the same. Hitherto students have, for the most part, been treated simply to lectures and exercises, with few or no opportunities of handling tools or electrical and magnetic appliances. Now, however, a new and most praiseworthy feature in the teaching of this subject is fast coming into vogue in Schools and Colleges, whereby students have not only to make their own apparatus, but to take laboratory notes of the results obtained. There can be no doubt that a combination of lectures, exercises, practical workshop and laboratory testing creates the most lasting impressions and the most thorough understanding in the minds of students. It often happens that a lad, comparatively dull in the lecture-room, will pull ahead of his more theoretically advanced fellow-students in the workshop and laboratory, and ultimately become the better Electrician or Electrical Engineer.

The different parts of the book may be taken up in any order most agreeable to the teacher, but a continuous experience of ten years' lecturing on this subject has proved to the Author that it is preferable to begin with Magnetism, on account of the greater ease with which fresh or elementary students understand and appreciate the magnetic phenomena. Moreover, since the session generally commences in October, the early winter months

in this country, owing to the natural humidity of our atmosphere, with its attendant fogs, are most unsuitable for successful experiments on Frictional Electricity. Magnetism naturally leads on to Electro-Magnetism and the laws of Current Electricity, and the student here gets a grasp of the accepted notions of potential, resistance, positive, and negative Electricity, &c., and is thus better prepared to follow and understand the peculiar phenomena observable when dealing with high tension or high pressure electricity in a statical condition.

The book, as a whole, will form an easy introduction to the Author's more Advanced Text Book upon the same subject, now in preparation. In the latter, a knowledge of Elementary Mathematics will be assumed, whereas in the present Manual any youth who has merely had a course of Elementary Arithmetic will be able to follow the expositions from beginning to end.

Of course, I have been indebted to other writers on the subject, but, at the same time, I have endeavoured, as far as possible, to carry out the method (adopted in my Lectures to my own students) of drawing attention to the *practical applications* of experimental facts in Telegraphy, Telephony, Electric Lighting, Transmission of Power, Electro-Metallurgy, &c. Most of the figures have been specially drawn for this book to represent the forms in which they are used at my Lectures. I have to thank my Electrical Assistants—Mr. James Livingston, A. Inst. E.E., Mr. Thos. Crichton Fulton, Mr. Ernest Payne, B.A. (Cantab.), and Mr. Philip S. Stewart, Wh. Exh., for kind assistance in the preparation of this little work.

If any errors should be observed by readers, or if they will kindly send me any suggestions or communications tending to increase the usefulness of the book, I shall feel greatly obliged for an early note of them, and will gratefully acknowledge the receipt of the same.

ANDREW JAMIESON.

THE GLASGOW AND WEST OF SCOTLAND
TECHNICAL COLLEGE,
September 1889.

PREFACE TO THE SECOND EDITION.

ALL errors observed in the first edition have been corrected, and all the Elementary Questions set at the 1890 and 1891 Science and Art Department's May Examinations have been printed at the end of the respective Lectures to which they most naturally belong.

A. J.

September 1891.

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LECTURE VI.

LECTURE VII.

LECTURE VIII.

APPENDIX.

INSTRUCTIONS TO BE FOLLOWED IN THE WRITING OF HOME EXERCISES.

1. Put the date of handing in each exercise at the right-hand top corner.

2. Leave a margin an inch wide on the left-hand side of each page; and in the margin place the number of the question, and nothing more.

3. Leave a space of at *least* three lines between your answers for remarks or corrections.

4. Be sure you understand *exactly* what the question requires you to answer, then give *all* it requires, but *no more*. If unable to answer any question, write down its number and the reason why.

5. Make your answers concise, clear, and exact; and accompany them, whenever practicable, by an *illustrative sketch.*

6. Make all sketches large, open, and in the centre of the page, and do not crowd any writing about them.

> NOTE.—The character of the sketches will be considered in awarding the marks to the several questions. Neat sketches and an "Index to Parts," with the first letter of name of Part, will always receive more marks than a bare written description.

7. Every sketch must be accompanied by an "Index to Parts" written immediately beneath it, and must accompany the answer it is designed to illustrate.

> NOTE.—The initial letter or letters of the name of the Part must be used, and not A, B, C, or 1, 2, 3, &c.

8. Unless otherwise specially requested by the question, every sketch must be accompanied by a *concise* written description.

9. Every answer which receives less than *half* of the full marks awarded to it, must be re-written correctly for next evening, before the usual class work, and headed "*Re-written.*"

REMARKS.—Students are strongly recommended to write out the answer in scroll first, and then to compare it with the question. After committing it to their book, they should then read it over a second time, so as to correct any errors they may thereby discover. Reasonable and easily intelligible contractions are permitted. Students are invited to ask questions and explanations regarding anything they do not understand. Except in special cases, arrears of Home work *will not receive marks.*

N.B.—*Students who from any cause have been absent from a lecture, must send a post-card or note of explanation to the teacher. If they miss any exercise or exercises, they must state the reason (in red ink, or underlined) in their exercise books when handing them in next night. If these rules are not complied with, then marks will be deducted.*

ELEMENTARY MANUAL

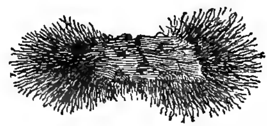
OF

MAGNETISM AND ELECTRICITY.

LECTURE I.

CONTENTS.—Natural Magnets—Artificial Magnets—How to Distinguish a Magnet—Definition of a Magnet—The Poles of a Magnet—How to Make Artificial Magnets—Specimen Question and Answer—Questions.

Natural Magnets.—It does not appear to be known who first discovered magnets. The word "magnet" is supposed, however, to have been derived from the name of an ancient district in Lydia, Asia Minor, called *Magnesia*, where a mineral and certain brown-coloured stones (now known as the magnetic oxide of iron, Fe_3O_4) were observed to possess the magic property of attracting small pieces of iron or steel. The Chinese claim to have discovered that when a piece of this magnetic stone is freely suspended by a thread, it naturally takes up a definite position, pointing nearly north and south, and they have been credited with being the first to make use of this device, in A.D. 1122, for the purpose of assisting them in navigating their ships. Hence the term *Lodestone*, or "leading stone," has been given to these natural magnets, which are found in various parts of the world, such as Sweden, Spain, the United States, &c., and from which class of ore excellent iron is obtained.



NATURAL MAGNET WITH IRON FILINGS.

Artificial Magnets.—If we take a piece of lodestone, and rub a bar of hardened steel with it, we shall find that the steel has been imbued with the magnetic properties of the natural magnet

without any apparent loss of magnetism in the stone. The strength of the magnetism found in lodestone is, however, not great, and since it cannot impart to the steel or artificial magnet a greater intensity of magnetisation than is possessed by the lodestone itself, we shall have recourse later on to more convenient and effective methods of making the magnets to be used in illustrating these Lectures.

EXPERIMENTS I.—**How to Distinguish a Magnet.**—Suppose you are given two bars of the same kind of steel, which are to all outward appearances alike in every respect, but the one is a magnet and the other is not; how would you find out which bar is magnetised?

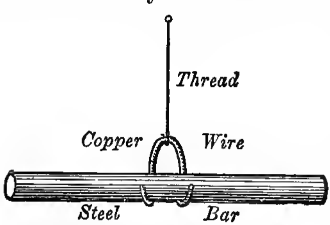
First, lay each piece of steel amongst iron filings, and then lift each of them clear of the filings. You immediately observe that some of the iron filings adhere to one of the bars, more especially to its ends, whilst the other has no filings attached to it.

MAGNETISED BAR WITH IRON FILINGS.

UNMAGNETISED BAR.

You conclude from this simple experiment that the bar which has attracted the iron filings is a magnet, and that the other is not. The magnetic force may, however, be so weak that few filings (especially if these are coarse) attach themselves to the magnet; consequently, now try another and more delicate test.

Second, suspend each bar horizontally by means of a fine thread, without any twist in it, and a copper-wire stirrup, as shown by the figure, keeping the bars a few feet apart, so that the magnetism of the one may not affect the other; you observe that one of the bars comes to rest with its length pointing in a northerly and southerly direction, and that, although you deflect it from this position, it always comes back to it again, whereas the other bar rests indifferently in any position. The former is evidently a magnet, whilst the latter is unmagnetised. We shall discuss in a future Lecture how it happens that the natural magnetism of the Earth acts upon the magnetised bar, and turns it until it takes up the definite position pointing nearly north and south.



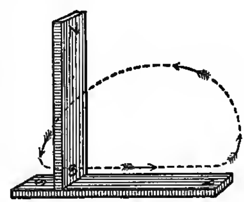
SUSPENDED HARD STEEL BAR.

Definition of a Magnet.—*A magnet is a piece of steel, or other magnetised substance, which possesses the properties of attracting other pieces of steel or iron or other magnetisable bodies, and of pointing, when freely suspended in a horizontal position, towards the poles of the earth.*

The Poles of a Magnet.—The ends of a magnet are termed *poles.* The end or pole which turns towards and points to the North, we shall call the "**North Pole,**" or **N-end,** or *marked,* or *red* end of a magnet; and the other, the "**South Pole,**" or **S-end,** or *unmarked,* or *blue* end.*

EXPERIMENTS II.—**How to Make Artificial Magnets.**†—Take a piece of hard steel (say $6'' \times \frac{5}{8}'' \times \frac{1}{4}''$) and make a mark near one end of it with a △ file. This end we wish to make a north pole.

1. *Magnetisation by Single Touch.*—Lay the piece of steel flat on a table, and take a strongly-magnetised steel bar magnet in the right hand, placing the unmarked or **S-end** of the same on the unmarked end of the bar to be magnetised. Then stroke the magnet along the steel bar to the opposite end, lifting it clear from the marked end, and letting it come down on the unmarked end in the direction indicated by the arrow and dotted curved line in the figure. Repeat this a dozen times. Now turn the steel bar on its side, and repeat the stroking process until all four sides of the bar have been acted upon. The bar of steel will then be found to be magnetised, having the marked or, N′, end as a north pole, since that end was always last touched with the **S-end** of the magnet.



SINGLE TOUCH.

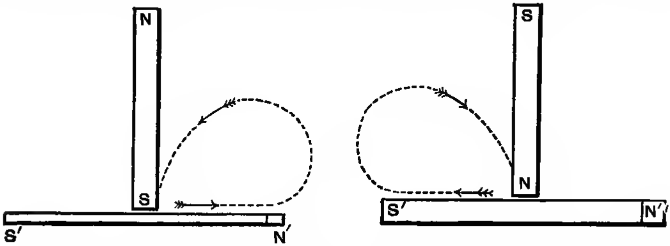
A better result may be obtained if one pole of the magnet be stroked from the centre of the steel bar to one end, and the other pole from the centre to the other end, following the directions indicated by the dotted lines and arrows in the two following figures. Then turn the bar over and repeat the process, until all four sides have been thus acted upon.

A horse-shoe shaped magnet may be used to magnetise a bar of steel of similar shape by simply placing a piece of soft iron across

* Makers of magnets usually stamp the north-seeking or north-pointing end of a magnet with the letter, **N**, or make a file-mark across that end, or paint it red, to distinguish it from the unmarked, south, or blue-painted end.

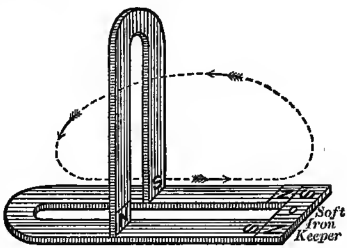
† See the Appendix to this section, "Magnetism," for a more detailed explanation.

the ends of the latter and stroking it with the magnet, following the direction of the curved dotted line and arrows as shown by the



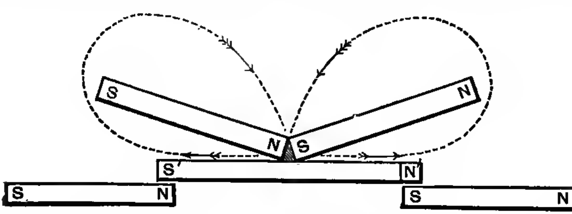
MAGNETISING EACH HALF SEPARATELY BY SINGLE TOUCH.

figure. When the $\cap$ bar being acted upon is turned over, care must be taken to also reverse the $\cap$ magnet so as to keep the opposite poles N and S next each other.



MAGNETISING HORSE-SHOE MAGNET.

2. *Magnetisation by Divided Touch.*—Place the steel bar, N′S′, to be magnetised, upon the ends of two bar magnets as shown



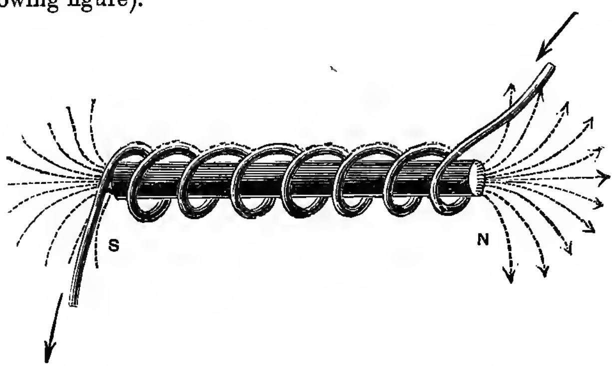
MAGNETISATION BY DIVIDED TOUCH.

by the figure. Take two other bar magnets, one in each hand (with their poles as marked), and holding them in an inclined

position simultaneously stroke the bar, N′S′, from the centre to the ends, following the direction of the dotted curved lines and arrows. Turn the bar, N′S′, over, and repeat the process a dozen or more times on each side, until it is as strongly magnetised as you can make it under the circumstances. This may be tested by trying the number or weight of nails which the bar under treatment will lift.

3. *Magnetisation by Double Touch.*—The only difference between this and the preceding method is, that the two magnetising bars are moved together with a piece of wood between them, their opposite poles being next each other. Now, with one set of ends of this double magnet, rub the steel bar to be acted upon from middle to one end backwards and forwards, finishing at the middle. Then rub from the middle to the other end, giving it the same number of rubs. Finally, do the same to each of the other sides until you have rendered it as strongly magnetised as can be effected.

4. *Magnetisation by an Electric Current.*—None of the previous processes will render a thick, large bar of steel a strong magnet. When a strong bar magnet is required, the hard steel bar should be placed inside a coil of covered copper wire (as shown by the following figure).



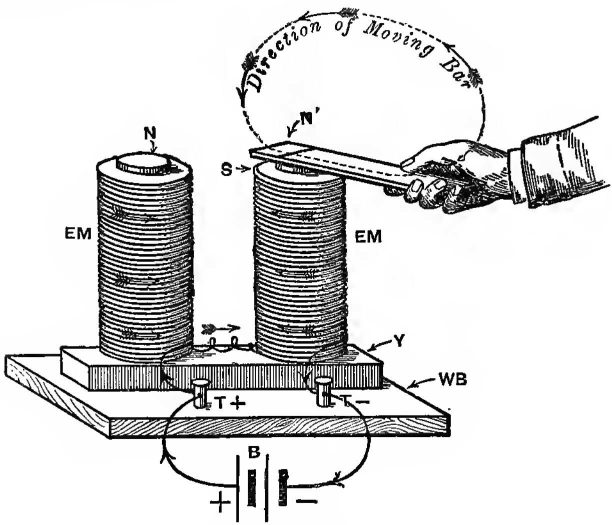
MAGNETISATION BY AN ELECTRIC CURRENT.

Through this coil a strong current of electricity is passed from any convenient source, such as a battery or a dynamo, and the ends of the bar are tapped with a hammer during the passage of the current.

Should it happen to be a horse-shoe shaped magnet that is required, insert first one limb into the coil, put on the current, tap the bar. Then take it out of the coil, and insert the other limb

into the opposite end of the coil; put on the current, tap the bar, take off the current and extract the bar, when you will have a magnet proportionately strong to the strength of the current employed and the number of turns of wire in the coil if the steel is not saturated.

5. *Magnetisation by an Electro-Magnet.*—Another very effective method is represented by the next figure, which illustrates the magnetisation of a bar of steel by an electro-magnet.



MAGNETISATION BY AN ELECTRO-MAGNET.

INDEX TO PARTS.

EM	represents	Electro-Magnet bobbins or solenoids.
NS	,,	North and South poles of iron cores.
Y	,,	Yoke of soft iron fixed to cores.
WB	,,	Wooden Base to which **Y** is fixed.
T+T-	,,	Terminals positive and negative.
B	,,	Battery or generator of electric current.
➳→	,,	Arrows showing direction of current.
N'	,,	North pole of bar being magnetised.

The construction and action of Electro-Magnets will be fully described in a future Lecture; but as this is a most useful piece of apparatus, its outward appearance and the method of using it for the purpose of making artificial magnets should be explained to the student at the very commencement of his studies of Magnetism;

for with it, he will get far better results than by any of the previous processes. An ordinary electro-magnet for lecture and workshop use consists of a, **U**, or horse-shoe shaped piece of very soft wrought iron, called the core, upon each limb of which is placed a bobbin or coil of covered copper wire. This combination is fixed to a wooden base, WB, and two of the ends of the coils of wire are joined together, whilst the other two are fixed to terminals marked, T +, and, T –, which in turn are connected to the ends of a battery, B, or other suitable source of electricity. When the wires are properly joined together and connected to the battery, the current of electricity which passes through the wire strongly magnetises the soft iron cores, with a north pole at one end and a south pole at the other as marked, **N**, and, **S**. All you have to do, is to clasp with the right hand the steel bar which you wish to magnetise, and stroke the bar from its middle to one end, as indicated by the curved dotted line and arrows, turning the bar quarter round after each stroke, so as to present each side of it to the core of the electro-magnet. Thereafter reverse the steel bar, and operate upon the other end with the other pole of the electro-magnet, until the bar will attract and lift two or three times its own weight of wrought iron.

Specimen Question and Answer.

Question.—You are required to magnetise a darning-needle so that the eye-end shall be a south pole. For this purpose, you are given a bar magnet, and are allowed to use *only* its south pole. How would you do so, and prove that you had done so correctly?

Answer.—Stroke the darning-needle several times from the centre to the point on the **S-pole** of the bar magnet, taking care to bring the needle back to its centre each time with a curve as indicated by the curved line and arrows in the figure.

[The student should make two neat freehand sketches in his note-book, the one to illustrate the experiment, and the other the proof. *Always give a sketch in answering a question if the answer admits of it.*]

Proof.—Suspend the needle near its centre by a fine thread without twist; if the needle (after being disturbed from its position) invariably comes to rest with its eye-end pointing southward, then you know that that end must have a south pole.

LECTURE I.—QUESTIONS.

1. State what you know about natural magnets. Where are they found? What name has been given to them, and why?

2. What is the difference between a natural and an artificial magnet? Can artificial magnets be produced by aid of a natural magnet? If so, how?

3. What do you understand by a magnet? What are its ends called, and why?

4. How would you ascertain whether a given piece of steel was magnetised or not?

5. You are provided with a bar magnet, and a steel knitting-needle, one end of which has been marked by a file or dipped into ink. State concisely (illustrating your remarks by freehand sketches) what you would do in order to magnetise the needle so as to make the marked end a **North** pole, and the other end a **South** pole. How would you find out whether you had succeeded?

6. Distinguish by sketches and concise explanation between the following methods of magnetisation:—(1) Single touch, (2) Double touch, (3) Divided touch.

7. You are given a coil of covered copper wire, a battery for producing electric currents, and a bar of hard steel in the form of a horse-shoe How would you magnetise the bar? Illustrate your remarks by freehand sketches.

8. You are provided with an electro-magnet, a battery, and a bar of hard steel. Explain and illustrate by a sketch how you would magnetise the bar. How would you find out which was the north pole of the bar when it was magnetised? and how would you test whether it was strongly magnetised or not?

LECTURE II.

CONTENTS.—Permanent Magnets—Common Forms of Permanent Magnets and their Uses (Simple Bar, Compound Bar, Simple Horse-shoe, Compound Horse-shoe, Horizontal Needle, Vertical Needle)—Attraction and Repulsion—First Law—Polarity—Specimen Question and Answer—Questions.

Permanent Magnets.*—In the last Lecture several well-known methods of magnetising steel were explained. All bar magnets, if made from the most suitable kind of steel properly tempered and magnetised, will permanently retain their magnetism, if care be taken not to subject them to rough usage or other demagnetising influences; and hence such magnets have been termed *Permanent Magnets*. Every kind of steel, however, will not make a good permanent magnet. In fact, steel containing a certain percentage of manganese refuses to become magnetised, whilst other kinds, such as certain brands of spring and cast steel, as well as mild plate steel, although easily magnetised, readily part with their magnetism. It, therefore, requires considerable knowledge of the different kinds of steel in the market, as well as practice in the different methods of tempering and magnetising, before an experimenter or a student can with certainty make really good, strong, permanent magnets. Even the very best permanent magnets that can be obtained from the best makers will become demagnetised if subjected to a high temperature, and they will part with a large percentage of their magnetism if carelessly permitted to come into contact with similar poles of other strong magnets, or roughly handled, or subjected to severe vibration, or suddenly severed from their soft iron keepers.

Common Forms of Permanent Magnets and their Uses.—*Simple Bar Magnets.*—As may have been gathered from the last

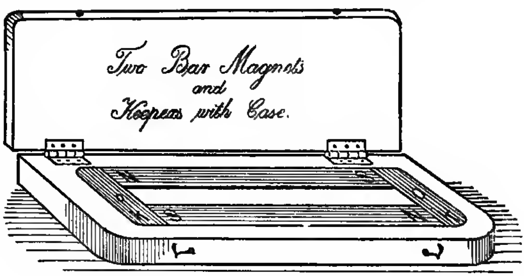
BAR MAGNET OF, ▭, SECTION.

* See Appendix to this section on Magnetism for a detailed description of how to select the best kind of steel, and how to treat it in order to make good *Permanent Magnets*, and *Magnetic Needles*.

Lecture, a permanent bar magnet is a plain solid steel bar, either rectangular or circular in section, which has been properly tempered and magnetised.

BAR MAGNET OF, O, SECTION.

For the purposes of class-illustration, as well as for simple laboratory instruction and experiments, it is found indispensable to have a pair of strong simple bar magnets, about 10 or 12 inches long, always at hand. When not in use, these magnets should be carefully inserted into a wooden case with their opposite poles, N, S, next each other, and with large wrought-iron *keepers*, K, placed across their ends as shown by the following figure.

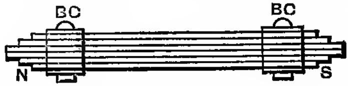


TWO BAR MAGNETS, KEEPERS, AND CASE.

The precise action of the keepers will be explained afterwards, but at present the student is simply informed that they help to prevent the magnets from losing their magnetism.

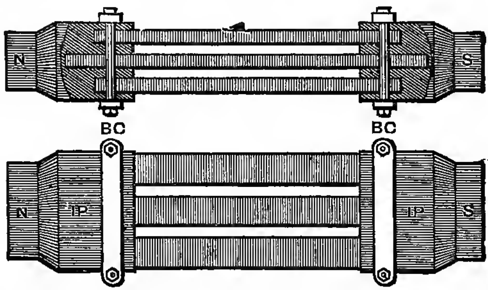
EXPERIMENTS III.—*Compound Bar Magnets.*—If a strong bar magnet be made of *one* piece of steel, $\frac{1}{4}$ inch or more in thickness, and then put into a bath, say, of nitric acid, whereby its surface is "eaten off," it will be found that the bar has lost the whole of its magnetism; thus proving that it is merely the surface-skin of the steel bar that has been strongly magnetised. The discovery that the strength of a magnet does not increase in simple proportion to its size, or, rather, that thin magnets are able to sustain a greater weight in proportion to their cross-sectional area than thick ones, naturally led to the introduction of what are termed "compound" magnets. Compound magnets are composed of very thin flat ribbons of hard steel, magnetised separately and fixed parallel

together (with their similar poles adjacent, and turned the same



Compound Bar Magnet.

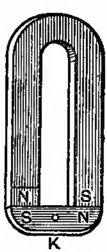
way) by means of brass clamps, BC, as indicated by the above figure. A more expensive form of compound bar magnet (illustrated by the following figure) is composed of nine thin bars arranged three on one side by three on the other. The ends of these bars are firmly embedded in and clamped to soft wrought-iron poles, IP, (by brass bolts and clamps, BC) so as to concen-



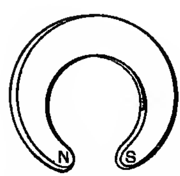
Compound Bar Magnet with Wrought-iron Poles.

trate and direct the magnetism from the separate bars into each of these common pole-pieces, N, and, S. Should magnets of either of the above compound forms lose their magnetism from any cause, then they can easily be taken to pieces, and the elementary bars be re-magnetised separately, and then put together again.

Simple Horse-shoe Magnets.—A simple permanent horse-shoe



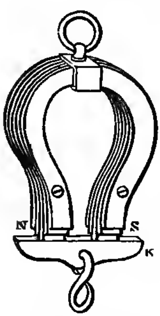
Horse-shoe Magnet of Section with Keeper.



Horse-shoe Magnet of Section without Keeper.

magnet consists of a plain solid steel bar, either rectangular or circular in section, that has been bent into the form of a horse's shoe, tempered, and magnetised.

Horse-shoe shaped magnets are useful for many practical purposes besides the mere illustration of the fact that a greater weight of iron or steel can be lifted by a magnet of this form, than can be lifted by one of the bar type, although both may be of the same sectional area, weight, and magnetic strength. This leads us to state here that the absolute "*strength*" of a magnet is not measured scientifically by the weight of iron or steel that it will lift, but by the quantity of free magnetism at either pole. How this quantity of free magnetism is measured and reckoned, must be left unexplained until the student has mastered the elementary stage. It will, however, be quite easily understood that, given a certain strength or attractive force at *each* pole of a magnet, if both poles can freely act *simultaneously* upon the attracted substance, a greater weight of the substance will be lifted than if only one pole were brought into action at one time. We may apply the illustration thus:—If a person can lift a certain weight with one of his hands, he will be able to lift about double this weight with both hands, if both hands can be simultaneously and effectively brought to bear on the weight. The load which a magnet can lift, therefore, depends not only upon the strength of its poles, but also upon the shape of the magnet, *i.e.*, upon the freedom with which one or both poles can bring their magnetic strength to bear upon the load. A *very* good steel *horse-shoe* magnet will lift about twenty times its own weight of soft wrought iron, being about four times the weight that can be lifted by a *straight* bar magnet of the same material and linear dimensions.



COMPOUND HORSE-SHOE MAGNET, N, S, AND KEEPER, K.

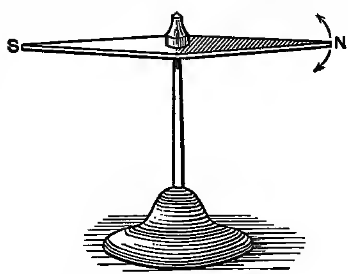
Compound Horse-shoe Magnets.—For precisely the same reasons as were given under the heading, "*Compound Bar Magnets*," we find that, when a very strong permanent horse-shoe magnet is required, recourse is had to the device of clamping several thin plates of magnetised steel together. It must be borne in mind, however (and the causes will be explained when we come to discuss magnetic induction), that the load of iron which a compound magnet will attract and lift is not so great as the sum of the loads lifted by each separate plate of which the magnet is composed. In testing the truth of this statement by experiment, it is well to remember that the keeper, K, should fairly butt

close up against *all* the N and S ends of the plates forming the compound magnet, and not merely in contact with the central plate, as shown by the last figure.

EXPERIMENT IV.—Another curious and interesting experiment may now be tried, viz., attach a pail or scale pan to the hook of the keeper, and very gradually add small additional weights by dropping an ordinary No. 6 gun shot every minute or so into the pail or pan. The ultimate weight which the magnet will support is much greater than the weight which it could bear at the commencement of the experiment; but whenever the keeper has been severed from the poles, their attractive force is again reduced to the original value, if not slightly below that amount. This peculiar behaviour has never received a satisfactory scientific explanation.

Horse-shoe permanent steel magnets are very useful wherever strongly concentrated magnetism is desired without having recourse to electro-magnets. In Sir William Thomson's Siphon Recorder for receiving messages on submarine cables, in De Meriten's alternate current dynamos at The Foreland, May Island, and other lighthouses for generating electricity for arc lighting, and in many kinds of telegraphic relays and receivers and telephonic transmitters, we find this form of magnet adopted.

Horizontal Magnetic Needle.—This useful piece of apparatus consists of a thin piece of magnetised steel usually in the shape of an elongated lozenge with a small hole bored through its centre. Into this hole is fixed an agate, glass, or brass centre (Λ) according as the needle is desired to be delicate or rough. The combined needle and centre are poised upon a fine hard steel point fixed into a wooden or brass base, so that the former may move with a minimum of resistance in a horizontal plane.

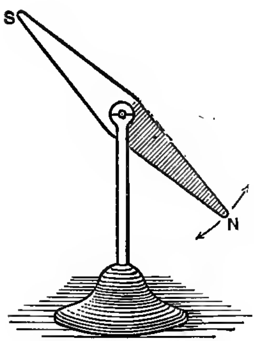


HORIZONTAL MAGNETIC NEEDLE.

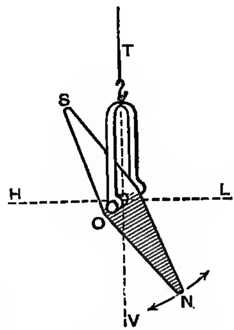
This form of magnet is much used in instruments for detecting and measuring electric currents. When attached to the mariner's card, it forms the well-known nautical compass, by means of which the steering of ships is regulated; consequently, without this little simple magnetic needle, the sailor would have a very much more difficult and dangerous task.

Vertical, Inclination or Dip Needle.—This form of magnetised

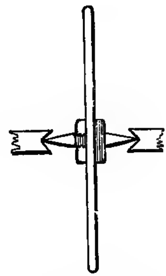
needle has its centre, or axis, so adjusted and supported that the needle can only move freely in a vertical plane. The needle is generally of the same shape and constructed in the same manner



DIP NEEDLE AND STAND.



DIP NEEDLE AND SUSPENSION.



END VIEW SECTION THROUGH BEARINGS.

as the horizontal needle just described. The centre, however, instead of being a single bearing, is either a fine axis fixed to and protruding on each side of the magnet, as illustrated by the above left-hand figure; or, it is pointed and rests in, **V**, agate, glass, or brass centres as shown by the right-hand figure.

The single needle telegraph instrument as used at many railway stations and signal boxes, is an instance of the practical application of this form of needle, and as we shall see when we come to discuss the subject of the "Earth as a Magnet," there is an interesting scientific piece of apparatus called the "Dip Needle and Circle" which also embodies this kind of needle.

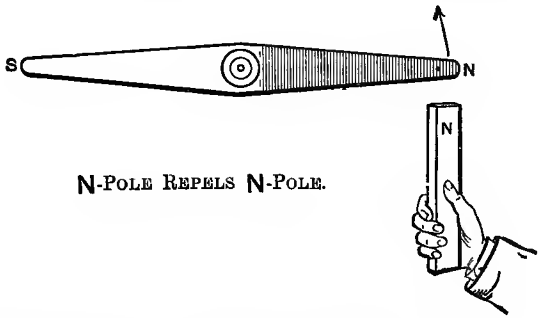
EXPERIMENT V.—**Attraction and Repulsion.**—(1) Suspend a simple bar magnet in the way described in the last Lecture, and thus find out its **N** and **S** poles; mark them.

(2) Take a magnetised needle of either the horizontal or vertical type, as described above. Find out in the same way their **N** and **S** poles, and mark them.

(3) Present the **N**-pole of the bar magnet to the **N**-pole of the needle, and observe its deflection away *from* that end of the bar magnet.

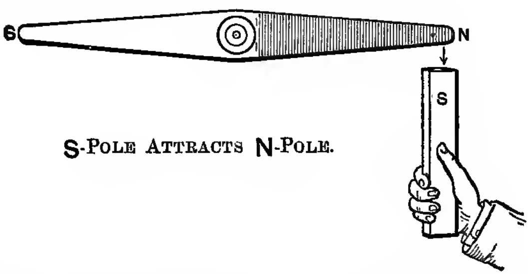
(4) Present the **S**-pole of the bar magnet to the **S**-pole of the needle, and again observe the *repulsion* of the needle.

(5) Present, however, the **S**-pole of the bar magnet to the



N-Pole Repels N-Pole.

N-pole of the needle, and observe that the needle now deflects *towards* the bar or exhibits *attraction*.



S-Pole Attracts N-Pole.

First Law.—Hence the law for attraction and repulsion between magnets is—

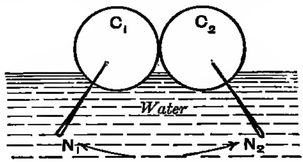
Like Poles Repel, but Unlike Poles Attract each other.

Polarity.—The term *Polarity* has been adopted to express this duality or two-endedness, or distinctive manifestations of the two poles of a magnet.

Specimen Question and Answer.

Question.—Two sewing-needles are magnetised so that the eye of each is a **N**-pole. The needles are stuck by their points into separate bits of cork, so that when each is thrown into water it floats upright with the eye downwards. How will the needles behave towards each other when the corks are *brought close together* in the water?

Answer.—As indicated by the following sketch:—



Where—

C_1, C_2, stand for the corks.
N_1, N_2, „ „ needles.
$\leftarrow \rightarrow$ „ „ repulsion.

Lecture II.—Questions.

1. What are permanent magnets? Of what are they made, and how?

2. Sketch and describe the construction of a simple and of a compound bar magnet. How would you prove by an experiment that it is only the surface of a bar of steel that is strongly magnetised? Deduce from your experiment the advantage of making strong magnets of thin ribbons or fine wires of steel.

3. Sketch and describe the construction of a simple and of a compound horse-shoe magnet. Name three practical applications of horse-shoe magnets.

4. Sketch and describe a horizontal and a vertical magnetic needle, and name two different practical applications of each.

5. If required to demonstrate the law that "like" magnetic poles repel, and that "unlike" poles attract each other, how would you do it? Give sketches.

6. A steel sewing-needle is drawn over the north pole of a magnet from eye to point. What is the subsequent condition of the needle? The point is now presented to the north pole of a magnetic needle; state what occurs. Illustrate your answer by a sketch.

7. Two long magnets, made of small steel wire, are suspended from their upper ends by threads, so that their lower ends are on a level with each other. Suppose the lower ends to be both north poles, how will the magnets act upon each other? Again reverse one of them, and sketch how they will now act upon each other.

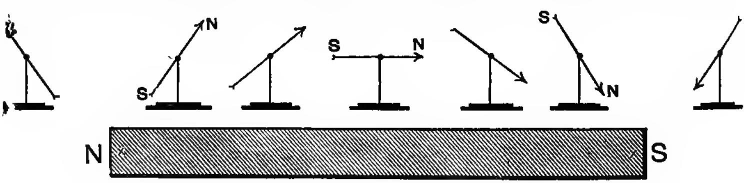
8. What do you understand by the polarity of a magnet?

LECTURE III.

Contents.—Magnetic Curves or Lines of Force—External and Internal Magnetic Fields—Second Law—Graphic Representation of Magnetic Fields—Different Cases of Magnetic Curves—Magnetic Axis and Magnetic Equator of a Bar Magnet—Specimen Question and Answer—Questions.

In Lecture I. we described how magnets are made, in Lecture II. we explained and illustrated common forms of magnets. We shall now give details of how the directions of the force which emanates from and surrounds magnets may be found by simple experiments.

Experiments VI.—**Magnetic Curves or Lines of Magnetic Force.**—*First*, take a *long* bar magnet and a short vertical or dipping needle of the form first illustrated and explained in the last Lecture. Lay the bar magnet flat upon a level table, and place the base of the needle-stand on the middle of the bar magnet. Observe that the needle lies horizontal, with its **N**-pole pointing in the direction of the **S**-pole of the bar magnet.* Now move the needle along the bar to the different positions indicated by the following figure, and observe how the needle dips more and



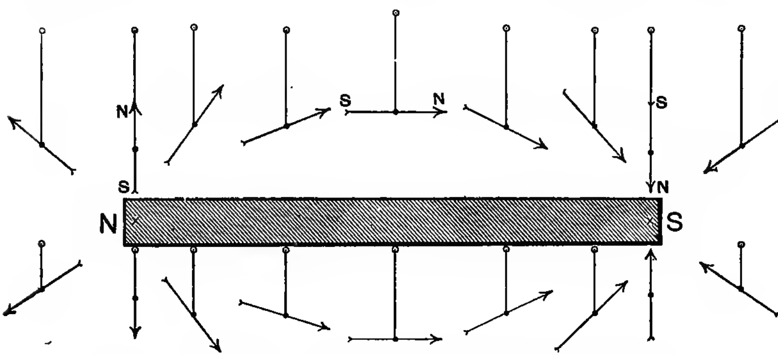
Testing for the Directions of the Magnetic Force Above a Bar Magnet.

more as it approaches the ends, becoming *truly vertical* when close to either end. Carry it beyond the ends, and it still inclines towards a point near to but slightly within the end of the bar to which it is nearest. This clearly manifests that there are invisible forces acting between the bar and the needle, and further that the

* The student should note that when it is required to illustrate a small magnetic needle, an arrow-head is invariably used to denote the **N**-pole of the needle.

lie of the needle indicates the mean or resultant direction of these forces.

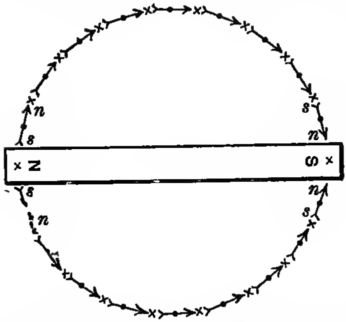
Second.—You may, however, say, Is this the case for the under, as well as the upper, side of the bar magnet? Yes, it is also true for the under side. In order to prove this, suspend or elevate the bar a foot or two above the table, still maintaining its horizontal position. Now take the needle (or for the sake of variety take the second form of vertical needle illustrated in last Lecture, or tie a fine thread to the centre of a short magnetised sewing-needle) and bring it over as well as under the bar to the several positions indicated by the following figure. You find that the needle dips to the poles from below as well as from above the bar when brought towards the ends, and lies horizontal at the centre.



FINDING DIRECTIONS OF MAGNETIC FORCE ABOVE AND BELOW A BAR MAGNET.

Third.—You may now say that, this proves *only* a directive force acting on the needle when it is placed above and below the flat sides of the bar magnet. Does this force exist on all sides as well as at the ends? Yes, it exists in every plane. For, turn the bar magnet on its edge, and you will get similar results to those last observed. Or, perhaps, a still more conclusive proof will be to lay the bar magnet down flat on a sheet of white paper upon a table, taking the end of the thread attached to the short needle in your left hand and holding it up until the needle almost touches the paper. Now, move the thread until the needle is brought into the various positions indicated by the following plan, and mark by means of a pencil (held in the right hand) small crosses (× × ×) at the places where the **N** and **S** poles of the needle come to rest. Remove the needle and join by short lines the various crosses

(× × ×), when you will have a couple of curves, one on each side of the bar magnet, like that shown below, which graphically represents the resultant directions of the magnetic forces along these two paths. You may go still further, for you may hold the thread in several different sets of positions, and thus plot out the directions of the magnetic lines or "curves of force" for any number of positions *all round about the magnet* in this plane, and then by turning the magnet first partially, and finally fully over, on its side, do the same for all these different planes, thus proving conclusively that the force of magnetism emanates in all directions from a magnet.

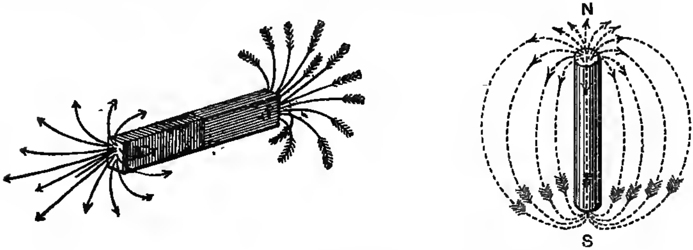


PLAN.—FINDING DIRECTIONS OF MAGNETIC FORCE ON THE SIDES AND ENDS OF A BAR MAGNET.

External and Internal Magnetic Fields.—The magnetic force which we have just proved to exist on all sides of a bar magnet is assumed by physicists and electricians to start from the **N**-pole, and to pass through the surrounding medium, entering the magnet by the **S**-pole, and completing its path through the magnet itself to the **N**-pole, thus forming a complete circuit.

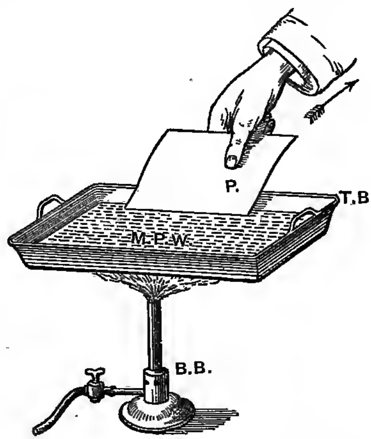
Second Law.—*No magnetic line or curve of magnetic force can exist without completing its own circuit, and magnetic lines or curves never cut, cross, or merge into one another.* Consequently, a magnet is never found, and cannot be made, with a single pole. One portion of the magnetic circuit lies *outside* the magnet, and the remainder is *inside* the magnet. The space *outside* the magnet throughout which its magnetism acts (as graphically represented by "the lines or curves of force" in the foregoing and following experiments) is termed the "*External Field*," or "*Apparent Field*," or shortly the "*Field*." The space occupied by the magnet may be termed the "*Internal Field*," or "*Non-apparent Field*." The cross-section of the magnet or internal field being, as a rule, less, and its natural aptitude for accommodating or conveying magnetic lines being much greater than the external field or air, there is, of necessity, great crowding or concentration of the lines of force where they leave the **N**-pole and where they enter the **S**-pole. The magnetism is therefore, found to be more intense at the poles than in other parts of the external field. This is very well illustrated by the two following figures, which

represent a magnet as if it were an arrow-sheath, with the arrows entering by the **S**-pole and leaving by the **N**-pole.



MAGNETIC LINES OF FORCE LEAVE AND ENTER A MAGNET ON ALL SIDES.

EXPERIMENT VII.—**Graphic Representation of Magnetic Fields.**—In order to represent graphically or map out magnetic fields for any particular form of magnet, or combination of magnets, take a foolscap sheet of strong impressed (unglazed), white paper, and draw it through a bath of *melted* white paraffine wax. Gently shake the paper over the bath so as to let the superfluous wax drop off, and hang the paper up by one corner to dry, whilst engaged treating several other pieces of foolscap in the manner just described.

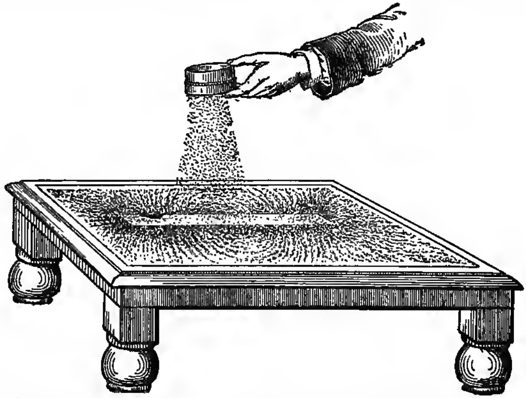


COVERING PAPER WITH PARAFFINE WAX.

P	represents	Paper.
TB	,,	Tin bath.
MPW	,,	Melted paraffine wax.
BB	,,	Bunsen burner.

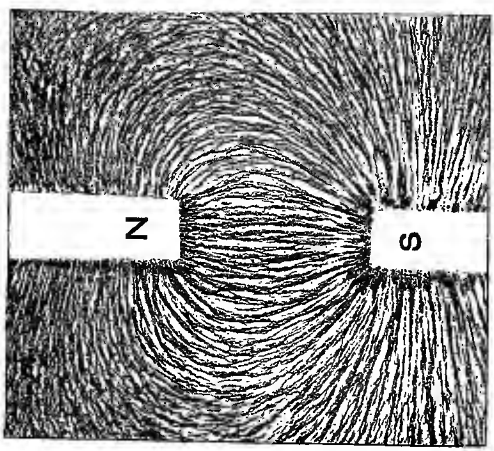
Now lay the magnet or magnets down upon a table in the precise way required, with pieces of wood of the same thickness as the magnet on each side of it, and upon these place the waxed paper. From a pepper-pot or muslin bag containing iron filings, held in the right hand about a foot or so above the paper, sprinkle the filings upon the paper, at the same time gently tapping the table. You instantly observe that the filings so arrange them-

selves as to form curves between the poles of the magnet or magnets, similar to the curves which were discovered by aid of



SPRINKLING IRON FILINGS UPON PREPARED PAPER.

Experiments VI. The fact is, that each iron filing when it comes within the influence of the external magnetic field of the magnet or magnets, becomes a small magnet by induction,* and of



PHOTOGRAPHED FROM A SPECIMEN CARD OF MAGNETIC FIELD MADE IN ACCORDANCE WITH THE PREVIOUS DIRECTIONS BY ONE OF PROFESSOR JAMIESON'S STUDENTS.

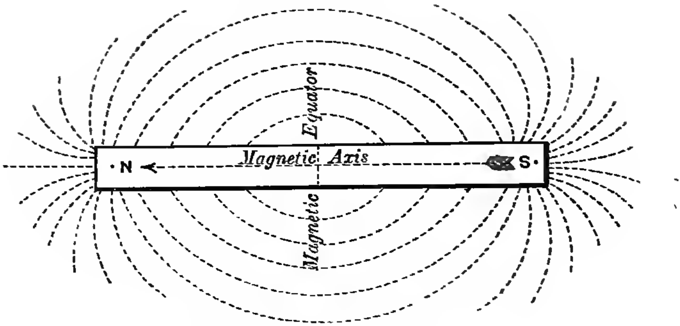
* This inductive action of magnets upon iron will be explained in a future Lecture.

necessity takes up a definite position under this influence or force in the same way that the magnetic needle did. When a sufficient quantity of filings has been showered upon the paper, so that the delineation of the whole magnetic field in that plane has been rendered apparent, pass a hot copper soldering-bolt, or the flame from a Bunsen burner, over (close to, but not touching) them. This melts the wax, and fixes the filings in their position, and they now present a permanent and beautiful picture of the resultant direction at every point and the relative intensity of the magnetic lines of force in the plane of the paper.

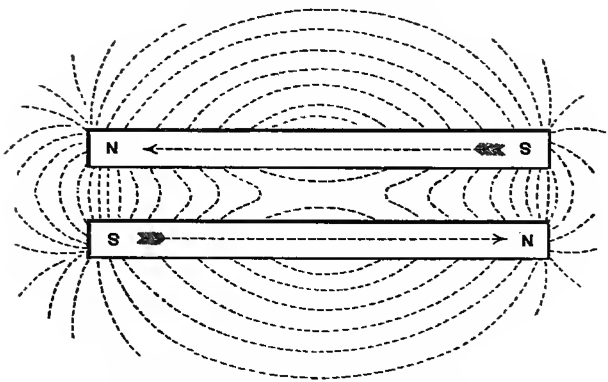
There are several other methods of obtaining the same result. A sheet of glass thinly gummed and dried may be used instead of the paper, and when the filings have been sifted over its surface (with due attention to tapping), a jet of steam is caused to play gently over the surface of the glass, which softens the gum and thus fixes the filings in their places. Or, the well-known blue ferro-prussiate paper used by draughtsmen for obtaining photo prints of drawings, may be used instead of the waxed paper. When the filings have been peppered over its surface, the whole is exposed to sun-light or to an electric arc-light for a short time. The filings are then shaken off and the paper washed with a fixing solution, when the curves will appear white on a deep blue ground.

Different Cases of Magnetic Curves.—The following figures are intended to illustrate a few of the simpler and more common cases of magnetic fields. All of these cases can be easily demonstrated and made apparent to a large class by means of the first process described above, or recourse may be had to a magic lantern, whereby the gradual delineation of the field may be most interestingly and instructively exhibited to an audience. Each of the following figures should be carefully copied by the student, or he should be encouraged to make them experimentally, and to see clearly for himself how the *First and Second Laws of Magnetism* hold good in every instance. When he has mastered the Laws of Magnetic Induction and of magnetic fields due to electric currents, his teacher may with advantage request him to predict by diagrams the direction and relative intensities of magnetic fields which would result from different arrangements of permanent magnets, and of electro-magnets with pieces of steel or of iron placed in various positions relatively to the magnetic field.

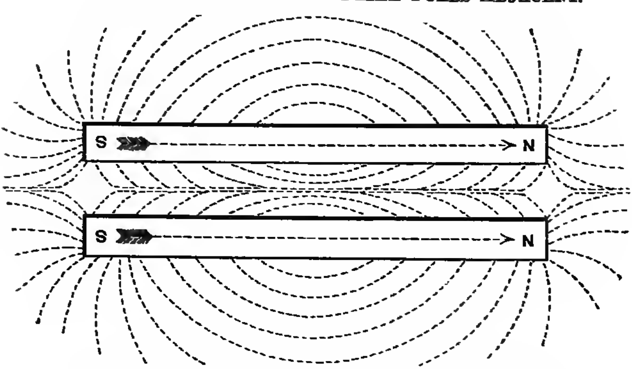
Magnetic Axis and Magnetic Equator of a Bar Magnet.—The straight line joining the **N** and **S** poles of a bar magnet is termed the Magnetic Axis of the magnet, and the line at right angles to this axis at the centre of the magnet where no free or external magnetism is apparent, and consequently where no iron filings are attracted, is termed the Magnetic Equator of the



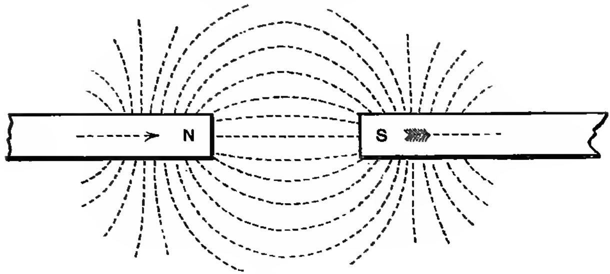
SIMPLE BAR MAGNET.



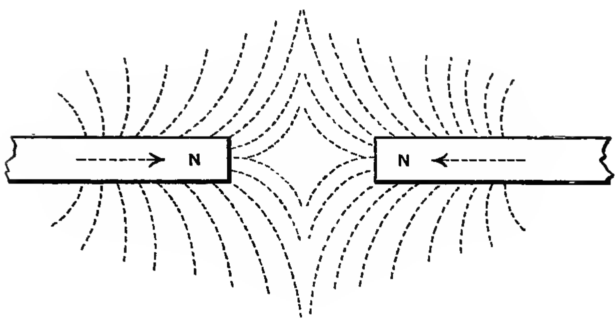
TWO BAR MAGNETS WITH UNLIKE POLES ADJACENT.



TWO BAR MAGNETS WITH LIKE POLES ADJACENT.

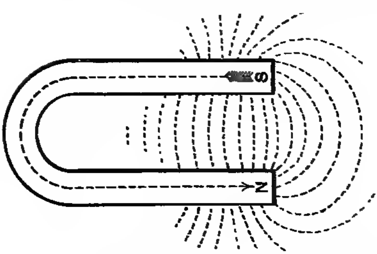


BAR MAGNETS WITH UNLIKE POLES OPPOSITE EACH OTHER.

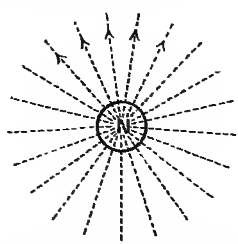


BAR MAGNETS WITH LIKE POLES OPPOSITE EACH OTHER.

Note.—In the above figures the remainder of the fields (between the N and S poles of each magnet) has been left out, due to want of space.



HORSE-SHOE MAGNET.



END OF CIRCULAR BAR MAGNET.

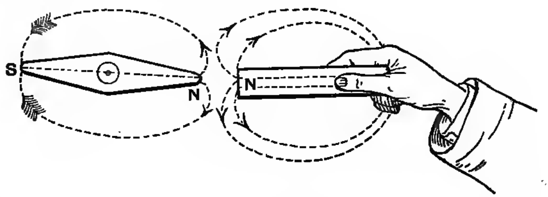
magnet. The positions of these two imaginary lines are shown by the first figure on p. 24.

Specimen Question and Answer.

Question.—A horizontal or compass-needle stands upon a table. You bring the North pole of a bar magnet towards it from the north. What happens, and why?

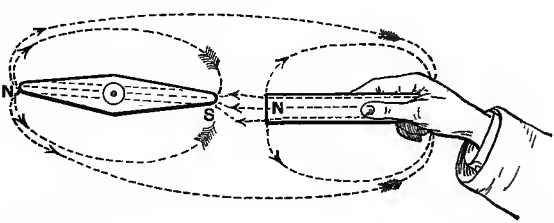
Answer.—The needle turns round until it takes up a position with its **S**-pole facing the **N**-pole of the bar magnet, for the following reasons:—

1. The compass-needle naturally lies with its **N**-pole pointing northwards; and, consequently, its lines of force issue in the opposite direction, and oppose the magnetic lines of force from the approaching bar magnet, thus—



Magnetic Lines from Needle and from Bar Magnet Complete their Circuits Independently.

2. The bar magnet, being held rigidly by the hand, cannot turn, but the needle, being freely suspended, is turned round in obedience to the forces or couple acting upon it, until a position is reached which naturally permits of the maximum lines of force from the bar magnet completing their circuits through it, as shown by the following figure:—



Some of the Magnetic Lines from Bar Magnet Complete their Circuit through the Needle.

Lecture III.—Questions.

1. Explain what you understand by a magnetic field. Distinguish between the external and the internal field in the case of a bar magnet.

2. Given a bar magnet and a freely suspended magnetic needle, how would you determine the paths of the lines of force which lie outside the former?

3. How would you prove experimentally that a magnetic field surrounds a bar magnet on all sides? Illustrate your answer by sketches.

4. Account briefly for the different behaviour of the lines of force in the two first figures on page 25.

5. Describe and illustrate a complete process whereby you can map out by aid of iron filings, and obtain a permanent record of the field of force surrounding a bar magnet in one plane.

6. A long strip of hard steel is magnetised; when your small magnetic needle is passed along the strip, its north pole is attracted by one end of the strip, its south pole by the other, the centre of the strip appearing to attract neither point of the needle. Explain this by aid of sketches.

7. What is meant by the magnetic axis and the magnetic equator of a magnet?

8. Sketch neatly how the lines of magnetic force arrange themselves in the following cases:—(1) A bar magnet; (2) two parallel bar magnets with *unlike* poles adjacent; (3) two parallel bar magnets with *like* poles adjacent.

9. Sketch neatly how lines of magnetic force arrange themselves in the following cases:—(1) A horse-shoe magnet; (2) two bar magnets in line with unlike poles adjacent; (3) two bar magnets with like poles adjacent; (4) one end of a bar magnet of circular section.

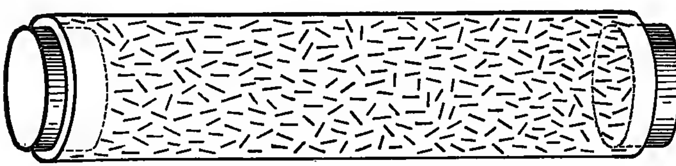
10. Suppose the south pole of a bar magnet, A, is brought near the north pole of a bar magnet, B, what change occurs in the directions of the lines of force about, A, and abont, B, and why? Illustrate your answer by sketches showing (1) the natural condition of the fields when A and B are far removed from each other; (2) when they are brought near to each other in a straight line; (3) when A is brought near to B, but at right angles to it.

11. Three precisely similar magnets are placed vertically with their lower ends on a horizontal table. Iron filings are scattered over a plate of glass which rests on their upper ends, two of which are north poles, and the third a south pole. Give a diagram showing the forms of the lines of force mapped out by the filings. (S. and A. Exam., 1889.)

LECTURE IV.

CONTENTS.—Molecular Theory of Magnetisation—Magnetic Saturation—Retentivity and Resistance—Effect of Vibration on Magnetisation—Effect of Temperature on Magnetisation—Questions.

EXPERIMENTS VIII.—**Molecular Theory of Magnetisation.**—In order to assist in comprehending what takes place when a piece of steel or iron is magnetised, take a glass tube (say 10 or 12 inches long and ½ inch internal diameter), and fill it lightly with steel or hard iron filings. Plug up the ends with corks and shake the filings.



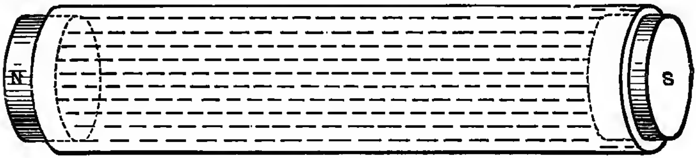
GLASS TUBE WITH UNMAGNETISED IRON FILINGS.

The filings present the appearance indicated by the above figure—in other words, they are not arranged in any definite order, but are mixed in a haphazard fashion.

First, present this tube of filings to a compass-needle; it will be found that each end attracts, and is attracted *equally* by, each end of the freely suspended needle. Or if you suspend the tube by a thread and stirrup (in the same way that we suspended the steel bar in Lecture I.), you will find that it comes to rest indifferently in any position. This proves that no free magnetism proceeds from the filings, or in popular language you would say that the tube of filings was not magnetised.

Second, place the tube inside a coil of insulated copper wire through which a strong electric current is passing, or strongly magnetise the filings as a whole by any of the methods described in Lecture I., and again present it to the compass-needle. You now find that one end strongly repels the **N**-pole of the needle, whilst it as strongly attracts the **S**-pole, and that the other end of

the tube repels the **S**-pole and attracts the **N**-pole, thus exhibiting all the effects of a permanent bar magnet.*

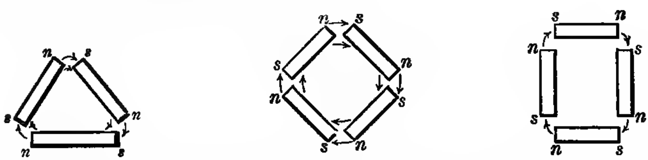


GLASS TUBE WITH MAGNETISED IRON FILINGS.

Or, if you now hang up the tube by the thread and stirrup, you will find that it always comes to rest with one end pointing to the north and the other to the south, just in the same way that a freely suspended permanent bar magnet does.

Third, mark one of the ends of the tube, say the north-pointing end, with a piece of chalk or with ink. Now shake the tube vigorously, so as to thoroughly intermix the iron filings, and then bring the marked end towards each end of the needle in turn, when it will be found to attract them equally (as will the unmarked end) just as in the first test. Or, suspend the tube as before, and it will come to rest indifferently in any position, thus proving that all free magnetism, or recognisable polarity, has disappeared from the filings. The whole is, therefore, no longer a magnet in the ordinary acceptation of the term, for the filings as a whole have become demagnetised.

What has happened may be thus explained. In the *first* and *third* cases, the iron filings were so arranged or rather disarranged that the lines of force proceeding from each found a short and easy path through its nearest neighbours. Their magnetic circuit was thereby completed *within themselves*, just as if they had been arranged like any of the three or four sets of small magnets in the following figures :—

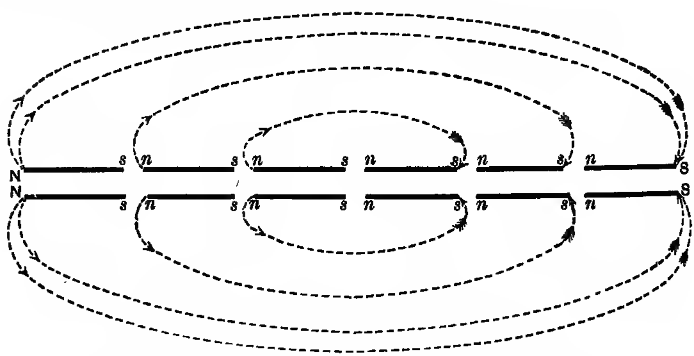


SHORT CIRCUITING OF MAGNETISM IN SMALL MAGNETS, EXHIBITING NEUTRAL CONDITION OF THE MOLECULES IN A MAGNETIC BODY.

* You *must always* observe a *repulsion* of one or other of the poles of the needle before you can be certain by this test whether a body is magnetised or not, *i.e.*, whether it possesses free magnetism or magnetic polarity. *Never depend solely upon attraction.*

The natural conditions of a magnetic circuit were therefore satisfied by a short circuiting of the lines of force between each of the neighbouring sets of small magnets or filings, and thus left no tendency to project their lines beyond themselves. In other words, the whole field was *entirely internal*, and without free magnetism.

In the *second* case, the filings having become turned round or symmetrically arranged (each one lying fair in line or parallel with its neighbours), the path of the magnetic lines springing from the set of *north* poles at the centre of the tube, found their easiest path to be through their neighbours in front of them, and so on towards the N-end of the tube. A rapid arithmetical accumulation of the lines of force thus took place, because each little filing or magnet not only projected its own set of lines, but conducted the lines of force from those immediately behind it. The naturally self-repellant action which like poles or lines in the same direction have for each other, forced some of the lines to take an external path before they reached the end of the tube. Those lines which did reach the end had no other route left for them but the air path, whereby to complete their circuit to the opposite end or free south poles. This condition of the *second* case is illustrated by the following enlarged sketch showing two sets of polarised filings or small magnets with external dotted lines to represent the external field. By referring again to the illustrations of magnetic curves at the end of the last Lecture, it will be seen how faithfully the above reasoning is borne out.



ENLARGED FIGURE OF THE CONDITION OF MAGNETISED IRON FILINGS IN THE GLASS TUBE, OR OF THE MOLECULES OF A MAGNET.

Another very interesting experiment to prove this same action, or partial rotation of the molecules of iron on their axes,

when a magnetising influence is brought to bear upon the bar, is that of mixing fine particles of the magnetic oxide of iron with water, and pouring the mixture into a glass tube fitted with clear glass ends. When the tube is shaken, you cannot see a light placed at its further end, but set the tube within a coil of insulated wire, and pass a current of electricity through the wire so as to magnetise the iron particles, and the light at once becomes apparent, from the fact that the particles arrange themselves longitudinally, as shown by the last figure, and thus offer less obstruction to the rays of light.

Magnetic Saturation.—In the case of a solid bar of steel, the molecules of which the bar is composed represent the mixed or higgledy-piggledy condition of the particles of hard iron or steel in the glass tube, only they are in much closer and firmer contact with one another. During the first stroke which the bar receives with a permanent magnet, some of the molecules are turned round a little and remain there; during the second stroke, a few more are turned round, and those that were already turned a little round are still further turned on their axes through a greater angle; and so on, until, when all the molecules have been fairly turned round, as portrayed by the last illustration, the bar is said to be *saturated* or completely magnetised, and, therefore, it will receive no more magnetism.

Retentivity and Resistance.—The rigidity with which the molecules remain in this stressed condition represents the *retentivity* or *permanency* of the material for magnetism. Generally speaking, the greater the retentivity of a magnetisable body, the greater the resistance to become magnetised. Thus, the harder steel is, the more difficult is it to magnetise, but its capability of retaining magnetism is correspondingly increased. This may be explained by the fact that the molecules of hard steel are very closely packed together, and consequently they are more difficult to turn from their natural position; but when once turned, their great intermolecular friction prevents their returning to the normal or neutral condition.

EXPERIMENTS IX.—Magnetise in turn first a bar of hardened steel, and then a bar of soft wrought iron of the same size and shape as the steel bar, by means of a coil of wire and the same current strength of electricity as explained in Lecture I. Without removing either bar when under the magnetising influence of the electric current, observe what weight of iron each will attract and lift. It will be found that the wrought-iron bar will lift a much greater weight than the steel bar, thus proving that iron is more easily and strongly magnetised than steel. Steel, therefore, offers a greater resistance to magnetisation than iron, and conse-

quently its natural *magnetic resistance** is said to be greater than that of iron.

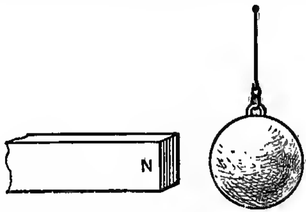
Effect of Vibration on Magnetisation.—Again, magnetise each of the bars in turn, and remove them from the coil, letting them fall several times roughly upon the floor; or hit them with a hammer so as to cause them to vibrate. Upon now testing them for magnetism with iron filings, or by aid of the compass-needle, it will be found that the soft wrought-iron bar has parted with its free magnetism, whereas the hard steel is still strongly magnetised. The molecules of the iron bar being more loosely put together are much more easily turned than those of the steel bar, and also regain their normal condition more readily. They represent in a marked degree the condition of matters previously illustrated by the tube of iron filings. In fact, the slightest shock or vibration is sufficient to demagnetise soft wrought iron. This property of being easily magnetised and demagnetised is largely taken advantage of in the practical applications of electricity and magnetism. For example, in the well-known Morse telegraph instruments, as well as in telegraph sounders, the cores of the electro-magnets are made of short pieces of soft iron, so that weak electric currents may quickly magnetise them, and that, when the current has ceased to flow, they may quickly lose their magnetism. The shorter the bar is, the quicker it will magnetise and demagnetise. Again, the armature-cores of continuous-current dynamo-machines are made up of thin plates of soft wrought iron, in order that they may readily become magnetised, demagnetised, and remagnetised, many hundred times in a minute.

Effect of Temperature on Magnetisation.—We have just seen that if the molecules of magnetised iron or steel are free to move and are vibrated, they become demagnetised. Now, when a body is heated, vibration is set up amongst its molecules, and the higher the temperature to which it is raised, the more rapid is the vibration; at the same time, the body expands, and thus permits of greater freedom of movement amongst its molecules.

EXPERIMENTS X.—Heat a steel magnet to 100° C., and you

* The single term "*coercive force*" was employed until lately by most writers to signify both the property of resisting magnetisation and of retaining magnetism; but the expressions *magnetic resistance* and *retentivity*, which have now become more general, are certainly more appropriate. The term magnetic resistance is very wide in its signification, and may be applied to all substances through which magnetic lines of force are caused to flow. Tables of the relative magnetic resistances of several different bodies (or their reciprocals, which are termed their *permeabilities*) have been derived from elaborate and accurate experiments, and are to be found in modern advanced treatises on magnetism. See Index to Munro and Jamieson's *Electrical Pocket Book*, published by Chas. Griffin & Co., for "*Permeability*."

will find that it loses some of its magnetism. Raise its temperature up to 700° C. or a bright-red heat, and it loses the whole of its magnetism. If, on the contrary, you decrease its temperature to freezing point or 0° C., the magnetism is increased in strength;



MAGNET AND RED-HOT IRON BALL.

but Prof. S. P. Thompson states that if the temperature is decreased to 100° C. below zero, the magnetism disappears. Heat a soft iron ball red-hot, suspend it by a chain or wire, and bring it near a strong magnet, you will find that the ball is not attracted by the magnet; when it cools down however, it becomes strongly attracted thereby.

Lecture IV.—Questions.

A glass tube, with its ends marked A and B, and nearly full of steel filings is stroked several times from A to B with the north-seeking pole of a strong magnet. The tube is then brought with its end B near to the south-seeking pole of a compass-needle. What is the effect upon the needle? The tube is now shaken so as to mix the filings, and put near the needle as before. What is the effect upon the needle? Why is the effect on the needle different in the two cases?

2. A glass tube, fitted with thin, clear, flat glass ends, is filled with water and a quantity of particles of magnetic iron oxide. The tube is shaken, and a lighted candle placed at one end cannot be seen from the other end of the tube; but when the tube is placed in a strong magnetic field parallel with the lines of force, the light now becomes clearly visible. Explain this.

3. How would you illustrate and explain the natural magnetic condition and relative position of the molecules of a bar of *unmagnetised* steel or iron?

4. How do you figure to yourself the change that occurs in a bar of unmagnetised steel when the pole of a magnet is rubbed along it? What do you understand by the pole of a magnet? Give sketches.

5. Explain and illustrate what is meant by saying that a bar of iron or steel has been *saturated* with magnetism.

6. A hard steel bar is said to have greater *retentivity* for magnetism than a similar bar of soft iron. How do you explain this?

7. A bar of hard steel is said to offer greater *magnetic resistance* than a bar of iron of the same size and shape. How do you explain this?

8. You have given to you two rods, one of soft iron, the other of hard steel; also a compass-needle and a bar magnet. Describe experiments with the things provided whereby you could find out which was the iron and which the steel rod. (S. and A. Exam., 1886.)

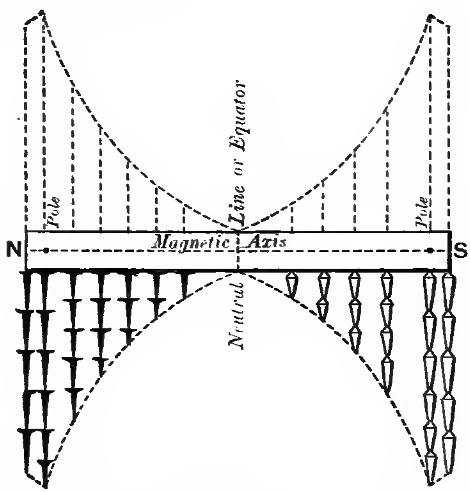
9 A bar of hard steel and a bar of soft wrought iron are both magnetised to saturation. Each bar is then hit hard several times with a hammer. What is the result in each case, and why?

10. If you make an iron ball red-hot, will it be attracted by a strong magnet? If you make a strong magnet red-hot, what is the effect? Give concise and clear reasons for your answers.

LECTURE V.

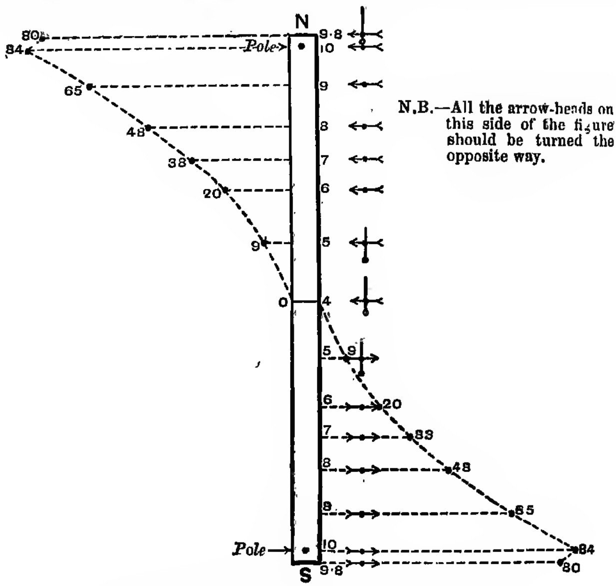
CONTENTS.—Distribution of Free Magnetism along a Bar Magnet—Another Proof of the Molecular Theory of Magnetisation. Breaking a Magnet—Magnetic Screens. Magnetic and Non-Magnetic Substances—Pole-Pieces—Armatures and Keepers—Specimen Question and Answer—Questions.

Distribution of Free Magnetism along a Bar Magnet.—By an inspection of the magnetic curves illustrated in Lecture III., and from what was explained in Lecture IV. regarding the paths of the lines of force through and from the molecules constituting a magnetised bar of steel, the student no doubt gathered that the relative strength or distribution of *free* magnetism along a bar magnet increases from nothing or zero at the centre, or neutral line, or equator of the magnet, to a maximum at the poles; and then diminishes slightly to the end of the magnet. We shall, however, endeavour to still further impress these facts upon him by two simple experiments.



ROUGH TEST FOR THE RELATIVE DISTRIBUTION OF FREE MAGNETISM ALONG A BAR MAGNET.

Experiment XI.—Take a long strong bar magnet and a number of small soft iron nails.* Firmly suspend or support the bar magnet, and commence by applying the nails to the underside of the magnet in chains, as shown by the figure on page 35. You will find that no nails are attracted at the neutral line or equator, that a gradually increasing number will attach themselves and hang on to each other as you get towards the poles, and that a less number will adhere to the very end of the bar than at a short distance inward from the end, thus proving that the quantity



Test for Distribution of Free Magnetism by Oscillations of Needle.

of free magnetism gradually increases from zero at the equator to the poles, and then diminishes slightly. On the upper side of the bar magnet have been drawn dotted vertical lines and outline dotted curves through their extremities, to graphically illustrate the relative quantities of free magnetism which also exist on that side; for, as we proved in Lecture III., lines of force proceed from a bar magnet in all directions.

Experiment XII.—Take a *long* bar magnet and fix it up vertically, with its **S**-pole pointing downwards, as shown by the

* French nails are best for this experiment.

figure on page 36. Place a *small* freely poised (or suspended and weighted) magnet capable of moving horizontally at each of the various positions close to the magnet, but always at the same fixed distance from it, as indicated on right hand of figure. Deflect the needle whilst held at each position, and count the number of complete oscillations (to and fro swings) which it makes in a given time; or, in other words, find the rate of oscillation for each position along the bar magnet. Now move the needle away from the magnet until it is quite beyond the influence of its magnet's field, and count the number of oscillations which it makes in the same time as before under the influence of the Earth's magnetism alone. This number will be the same as the needle made when opposite to the equator of the bar magnet, thus giving you another proof that no free magnetism is found close to and at the magnet's neutral line. Finally, *square the number of oscillations per minute as found at each position, subtracting from each square the square of the number under the Earth's magnetism alone, and you get a series of values representing the quantities of free magnetism along the bar.* If you take these final results and plot them to scale along a figure of the magnet, for each position, by lines drawn at right angles to the length of the bar magnet, then, by joining the extremities of these lines, you obtain two curves, the ordinates of which graphically represent the relative distribution of free magnetism along one side of the bar magnet, or the relative number of lines of force which leave the magnet at different points. For example, suppose that the magnetic needle gives 4 complete oscillations (or to and fro swings) in one minute when under the influence of the Earth's magnetism only; but that when opposite the pole of the bar magnet the needle gives 10 oscillations.

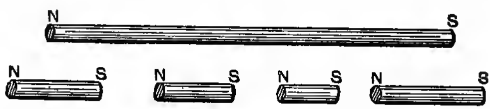
$$\text{Then, } (10^2 - 4^2) = 100 - 16 = \mathbf{84}.$$

Therefore 84 parts represent the length of the lines drawn at right angles to the magnet opposite the poles. And so on for all the other positions. Thus—

Oscillations.	Oscillations squared.	Oscillations squared minus Earth's Oscillations squared.	Relative Quantities of Free Magnetism.
At centre 4	16	16 − 16	0
„ 5	25	25 − 16	9
„ 6	36	36 − 16	20
„ 7	49	49 − 16	33
„ 8	64	64 − 16	48
„ 9	81	81 − 16	65
At pole 10	100	100 − 16	84
„ 9.8	96	96 − 16	80

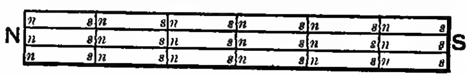
Another Proof of the Molecular Theory of Magnetisation.—Some of you may have been thoroughly satisfied from what was said in the last Lecture, explanatory of the similar magnetic conditions of the hard iron filings in the glass tube and a steel bar magnet, that the molecules of the latter are each complete little perfect magnets; but we shall here introduce one other simple experiment as an additional proof.

EXPERIMENT XIII.—Take a thin bar of magnetised steel, or a magnetised knitting-needle. Test its polarity by bringing it towards a compass-needle and mark its **N**-pole. Now break the magnet at the neutral line, or equator, into two parts, and test each half by the needle. You find that each part is a perfect magnet with **N** and **S** poles nearly as strong as the original whole magnet. The pole which was originally a **N**-pole is still *North*, and the pole which was originally a **S**-pole is still *South*, but we have a new **S**-pole and a new **N**-pole at the place of fracture. If you break each of the halves, and test them as before, you produce four complete magnets, as shown by the following figure:—



BREAKING A MAGNET AS A TEST OF THE MOLECULAR POLAR THEORY OF MAGNETISATION.

You may proceed in this way, breaking each piece into two, until you make them so very small that you cannot break them any further. Still, however small you make them you will find that each little bit is a complete magnet. You therefore conclude, not only that *a steel or iron magnet is composed of a congregation of tiny (molecular) magnets, each of which is a complete magnet; but also that it is impossible to produce a magnet with only one pole.*

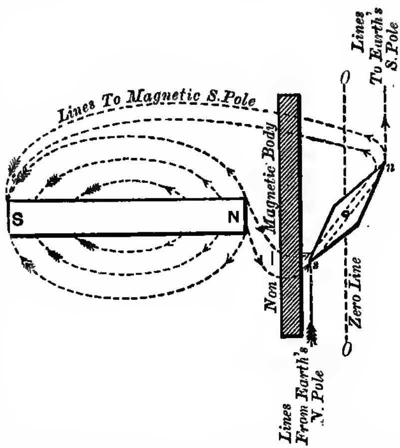


MAGNIFIED MOLECULAR POLAR CONDITION OF A MAGNET.

The above figure helps to convey the meaning of the foregoing remarks, and serves to indicate that wherever the magnet happens to be broken the fracture shows a **N** set of poles on one side and a **S** set on the other.

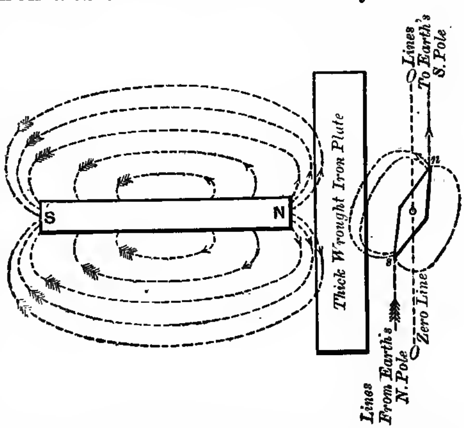
EXPERIMENT XIV. — **Magnetic Screens; Magnetic and Non-Magnetic Substances.**—Lay an ordinary compass-needle

down upon a table. It points in a north and south direction, under the influence of the Earth's magnetism, if no pieces of soft iron or other magnet be near to disturb it. Bring a long bar magnet up towards, and on a level with, the centre of the needle from the west or the east, until the needle deflects 45° to 50° from its former natural or zero position. Now interpose between the needle and the magnet, a board of wood. The needle still remains deflected to the same extent as before. Substitute in turn for the board of wood, a piece of cardboard, a sheet of brass or copper or ebonite, or a pane of glass, or a vacuum jar, and still the needle maintains its deflected position. But replace these by a thin sheet of soft iron and the deflection is sensibly reduced.



COMPASS-NEEDLE DEFLECTED BY BAR MAGNET, ALTHOUGH A NON-MAGNETIC BODY IS PLACED BETWEEN THEM.

Insert a very thick large plate of soft wrought iron and the needle now swings back to almost its zero position, but still slightly inclined towards the iron plate. The thick soft iron plate acts as a *magnetic screen*, shielding the needle from the force of the magnetic lines emanating from the bar magnet.



COMPASS-NEEDLE SHIELDED FROM MAGNETISM OF BAR MAGNET BY A THICK PLATE OF SOFT WROUGHT IRON PLACED BETWEEN THEM.

In the *first* case you observe that the interposition of

boards, plates, or slabs of wood, cardboard, brass, copper, ebonite, or glass produces very little more or less retarding or shielding effect to the magnetic lines of force which pass between the magnet and the needle, and *vice versâ*, than if the intervening medium had been air or a vacuum. These and many other substances are therefore termed *non-magnetic* bodies, in contra-distinction to iron, steel, nickel, cobalt, chromium, cerium, and manganese, which are *magnetic* or magnetisable bodies. What occurs is precisely similar to the action and reaction which always take place between a magnet and a compass-needle, and which was so far explained in answering the specimen question at the end of Lecture III. Before the magnet is brought near the needle, the lines of magnetism passing from the needle (to the Earth's poles and from the Earth's poles to the needle's) pull it round until they lie in a line with and flow in the same direction as those of the Earth's magnetic lines. Again, suppose for a moment that there was no Earth's magnetism present when the bar magnet is brought near the needle, the latter would swing round through 90° until its axial lines of force and those from the magnet were fairly in a line with each other and flowing in the same direction. Consequently, when the magnetic force of the Earth and that of the magnet simultaneously act upon the magnetism of the needle, the latter must take up an intermediate position so as to permit of its lines being shared between the Earth's poles and the magnet's poles in proportion to the respective strengths of their magnetic fields at the position of the needle. In other words, the needle takes up a resultant position under the action of two forces—viz., that due to the Earth and that due to the bar magnet. The stronger the bar magnet and the nearer it is to the needle the greater will be the deflection of the latter from zero, and proportionately more of the needle's and of the magnet's lines of force will pass through each other.

In the *second* case the whole of the lines of force (which in the first case passed from the magnet to and through the needle) find a path of less resistance through the nearer side of the thick soft iron plate, and therefore they do not reach or produce any effect upon the needle. Their force is occupied in magnetising a portion of the plate. In effecting this they naturally turn with the polarised iron molecules, and thus obtain a shorter circuit back to the further pole of the bar magnet as indicated by the last figure. The needle also being a magnet and being close to the other side of the thick iron plate produces a similar effect; but, being free to move, it deflects slightly from zero until its lines of force are proportionately accommodated between the Earth's magnetism and the induced magnetism in the plate. This deflection is,

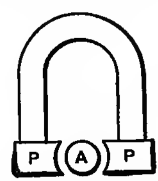
of course, small compared with the deflection in the first case, because the induced lines of force in the plate are few compared with the number of lines which reached the needle from the bar magnet. You can now understand that if a magnet is entirely surrounded by a thick hollow sphere of soft iron it will be entirely screened from the action of external magnets. Sir William Thomson takes advantage of this fact in his Marine Ironclad Galvanometer in order to protect the needle from the influence of the steel ship's and the Earth's magnetism by placing it and the coil of wire inside a cylinder of thick soft wrought iron.

Two important facts brought out by these experiments should be carefully noted and applied to reasoning out similar cases.

1. *Lines of force always choose the path of least magnetic resistance.*

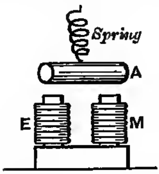
2. *If a magnetic body, free to move in any direction, be placed in a magnetic field, it always moves so as to accommodate through itself the greatest possible number of the lines of force of the field, in the same direction as its own internal lines.*

Pole-Pieces, Armatures, and Keepers.—From the previous experiments and remarks the student will have gathered that some of the magnetic lines of force which leave and enter a magnet extend to considerable distances in all directions from the poles; and that they are constantly exerting themselves to polarise all magnetisable bodies within their circuit. In order to concentrate or direct as many of the lines as possible from the poles of a magnet in a definite desired direction, the poles are often fitted with *pole-pieces* or extensions of wrought iron, cast iron, or steel, of a form most suitable for the special purpose in view. For example, the pole-pieces fitted to the compound bar magnet illustrated in Lecture II. are so arranged as to guide the lines of force from each of the separate plates of which the magnet is composed into one common channel at each end. In the following figure, the pole-pieces are shown bored out between the facing ends so as to concentrate the lines of force from the horse-shoe magnet upon a central iron-cored cylinder termed an *Armature.* The armature in the case of a dynamo-machine (or machine for generating electricity by means of mechanical power) consists of a soft wrought-iron core covered longitudinally with insulated copper wire. In the case of a Morse telegraph instrument the armature consists of a cylindrical tube of wrought iron, which is free to be attracted by the poles of the electro-magnet against the tension of a spiral



POLE-PIECES (PP) AND ARMATURE (A) OF A MAGNETO-ELECTRIC DYNAMO.

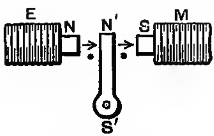
spring when the poles are excited, and to return to its normal position under the action of the spring when the poles become demagnetised. In telegraphic relays and other electrical instruments the armature consists of a piece of magnetised iron or steel so pivoted that one end may move between and be attracted or repelled by the poles of the magnet according as they are rendered **N** or **S**. In this case the armature is termed a polarised or permanently magnetised armature (see next figure).



ARMATURE (A) AND ELECTRO - MAGNET (EM) OF A MORSE TELEGRAPH INSTRUMENT.

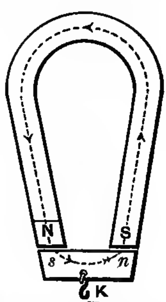
Generally speaking, then, an *Armature is a magnetic body, placed between or near, but not touching, the poles of a magnet; and which is free to be rotated, or moved to and from them or between them, by or against the concentrated magnetic force of the poles.*

A *Keeper* differs from an *Armature*, for it is a soft piece of wrought iron placed across and actually connecting the unlike poles of a horseshoe magnet (or of a pair of straight or curved magnets) for the purpose of concentrating the lines of force as entirely as possible upon itself. *You may therefore consider a keeper as a simple device for furnishing a complete short circuit or closed magnetic path for the lines of force between unlike poles of a magnet or magnets.*



POLARISED ARMATURE (N'S') OF A TELEGRAPHIC RELAY ELECTRO-MAGNET (EM).

The lines of force which pass from the magnet through the keeper polarise the latter, and thereby render the keeper a magnet with opposite poles to those of the magnet, as illustrated by the accompanying figure. The magnetism thus induced in the keeper reacts on, and induces further magnetism in, the magnet; so that the keeper not only helps to maintain, but also to strengthen, the magnet. Deprived of its keeper a magnet gradually loses its magnetism, for the stray lines of force (or those which make a long circuit between the poles) are very easily cancelled or lost by vibration, &c., from the fact that it is much



HORSE-SHOE MAGNET AND KEEPER, SHOWING POLARITY OF EACH, AND CLOSED MAGNETIC CIRCUIT.

easier to demagnetise than to magnetise steel. It may take more than a dozen strokes from a strong permanent magnet to strongly magnetise a bar of steel, but one or two strokes with the reverse pole will very seriously deprive the bar of its magnetism if they do not actually demagnetise it.

Specimen Question and Answer.

Question.—An iron ball is held over a pole of a horse-shoe magnet. Will the attraction exerted on the ball be altered if the poles of the magnet are connected by a soft iron keeper, and, if so, in what way, and why? (S. and A. Exam., 1889.)

Answer.—Yes. When the poles of the magnet are connected by a soft iron keeper all the lines of force between the poles are concentrated within, and find their circuit through, the keeper; consequently, no free magnetism is left to act inductively upon the iron ball.

Note.—The student should make two sketches to illustrate the above answer—

(1) Showing the direction of the lines of force when the ball is held over a pole of the horse-shoe magnet *without the keeper*, and marking the polarisation of the ball and direction in which it is attracted.

(2) Showing the path of the lines of force through the keeper, and the unpolarised unattracted ball.

LECTURE V.—QUESTIONS.

1. How does the middle of a magnet act upon a piece of iron? How do the ends of the magnet act upon the same iron? Does any change occur in the iron when the magnet acts upon it?

2. How could you ascertain the relative quantities of free magnetism which exist at different points along a bar magnet? Having found them by experiment, how would you plot them out so as to represent a continuous curve showing the variation from the equator to each pole of the magnet?

3. A long strip of hard steel is magnetised, and when your small magnetic needle is passed along the strip, its north point is attracted by one end of the strip, its south point by the other, the centre of the strip appearing to attract neither point of the needle. When the strip is broken across at the centre, what is the action of its two halves upon the magnetic needle? If each half is again broken, what happens, and why?

4. The pole of a magnet is brought within an inch of one side of a sphere of very hard steel. It manifestly attracts the steel, but is not quite able to draw it into contact. A sphere of iron of the same weight is now substituted for the sphere of steel, and the magnet is found able to draw this new sphere quite up against itself. Explain, according to the molecular theory, this difference of action.

5. If a compass-needle is deflected when a steel bar is brought near it, how can you find out whether the deflection is due to magnetism already possessed by the bar, or to the bar becoming magnetised by the compass-needle at the time of the experiment? (S. and A. Exam., 1886.)

6. Illustrate and fully explain the difference between, and the uses of, Pole-Pieces, Armatures, and Keepers.

7. What are magnetic keepers? Give the theory of their use.

8. A magnet is placed near a compass-needle so as to pull the needle a little way round. If a large and thick sheet of soft iron is put between the magnet and the needle, what happens, and why?

9. A horse-shoe magnet is placed near a compass-needle so as to pull the needle a little way round. On laying a piece of soft iron across the poles of the horse-shoe magnet, the compass-needle moves back towards its natural position. Explain this. (S. and A. Exam., 1885.)

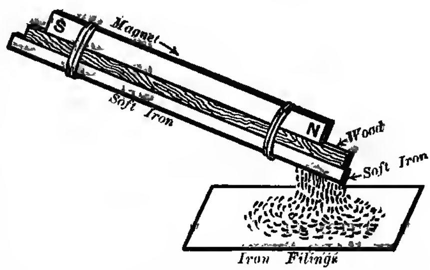
10. A piece of soft iron, placed in contact with both poles of a horse-shoe magnet at the same time, is held on with more than twice the force with which it would be held if it were in contact with only one pole of the same magnet. Why is this? (S. and A. Exam., 1886.)

11. You have three equal bar magnets without keepers. How would you arrange them so that, when not in use, they might preserve their magnetism? Give a sketch.

LECTURE VI.

CONTENTS.—Magnetic Induction—Definition of Induction—Secondary Induction—In the Case of Induction the Attraction always takes place between Two Magnets—Action and Reaction are Equal and Opposite—Inductive Effects of Like and Unlike Poles—Polarity Reversed, or Consequent Poles produced by Induction—Questions.

EXPERIMENTS XV.—**Magnetic Induction.**—Take a straight strip of soft iron (about 10 inches long and about 1 inch broad), and hold it close above some iron filings. No filings will be found adhering to the strip. Now lay along the strip a thin piece of wood, and on the wood a strong bar magnet of about the same length as the soft iron strip. Tie the three together with string, as shown by the figure. Again hold the soft iron close above the filings, taking care that the magnet does not approach too near them. This time it will be found that the iron strip has become a magnet, for it attracts some of the filings to itself, although it is not even touched by the magnet. This peculiarity possessed by magnetic force, of being able to act upon other magnetisable bodies at a distance, is known as *magnetic induction.*



SOFT IRON BAR MAGNETISED INDUCTIVELY BY BAR MAGNET.

DEFINITION.—*Magnetic Induction is the name given to the action and reaction which take place when the magnetic force springing from one body makes evident the latent magnetism in another body, either, with or without actual contact between the bodies.*

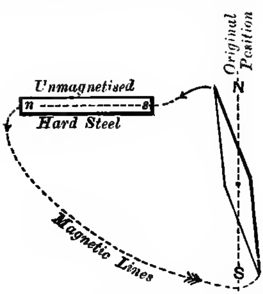
The body from which the force emanates is called the *inducing body;* while that upon which the force acts is called the *body under induction.*

Strictly speaking, there ought to be an interval or gap between the inducing body and the one which is under induction; but if

has become customary, in the case of magnetism, to extend the meaning of induction so as to include actual contact. The space between the bodies may be a vacuum, or it may be occupied by such non-magnetic substances as air, wood, glass, or copper; but one condition *must* be fulfilled—*whatever lies between must be non-magnetic.*

Secondary Induction.—Referring again to the experiment just performed, it will be noted that the filings were attracted even although the strip of iron did not touch them. This is an instance of the magnetisation of filings by the secondary inductive action of the force first induced in the soft iron by the magnet. And so, in every case of magnetic attraction, there must first of all be induction.

EXPERIMENTS XVI.—**In the Case of Induction the Attraction always takes place between Two Magnets.**—Procure a piece of very hard unmagnetised steel, and also a piece of good soft wrought iron of the same size and shape as the steel. Place a compass-needle on the table, and lay the steel bar on a level with it. You observe that the needle is slightly deflected from its natural position. Now, in accordance with a Law of Magnetism mentioned in a previous Lecture, that end of the bar which is nearer either pole of the needle must become a pole of opposite kind, for some of the lines of force from the magnetic needle have passed through the bar of steel, and have polarised it by giving its molecules a definite set. It thus becomes a magnet by *induction.* What appears, then, to be a simple piece of steel attracting a magnet, is in reality one magnet attracting another.



ATTRACTION OF NEEDLE BY HARD STEEL.

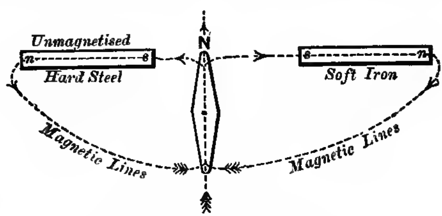
If, now, you substitute the iron bar in the place of the steel one, you will again have the needle deflected, but this time to a much greater angle than in the case of the steel bar. This is just what you might have predicted from what you had been taught by several of the previous experiments, for the less magnetic resistance of the iron naturally permits the induction to take place more easily. In this way you can determine roughly whether a sample of iron, or steel, has great or small magnetic resistance; or whether a bar is made of steel or of iron. The iron bar when under the influence of the needle's magnetism is a much stronger magnet for the time being than the steel bar. In each case, how-

ever, you find both *action* and *reaction* taking place. First there is the inductive *action* by the magnetism of the needle upon the bar, and then follows (as a second and necessary consequence) the *reaction* from this induced magnetism upon the needle causing the latter to be deflected. And, just as the inductive *action* was greater upon the soft iron, so also was the *reaction* correspondingly greater. You thus learn the important fact, that *in all cases of magnetic induction, action and reaction are equal and opposite.*

The tendency of the magnetic needle to attract the bar of steel or of iron was exactly equal and opposite to the attraction which they respectively exercised over the needle. The weight and position of the bars prevented the needle from moving them, but the force tending to do so was there all the same. The reaction of the magnetism evoked in the plate of soft iron by the needle in Experiment XIV. (last Lecture) explains why the latter did not quite resume its natural or zero position of rest, even after it was freed from the influence of the bar magnet.

Seeing that there is a greater intensity of field, or a larger number of lines of force within a certain space in the immediate neighbourhood of a magnet than there is within an equal space further away, you conclude that the shorter the distance between the inducing body and that under induction, the greater will be the inductive action. This may be proved by moving the bars nearer to, or further away from, the compass-needle, and noting how the angle of deflection varies.

An interesting variation of this experiment (as illustrated by the following figure) would be to balance the effect of magnetic resistance against distance, by placing one of the bars on each side of the same pole of the needle, and altering their distances therefrom until it was found that the needle was *not* deflected. You would thus prove that there was as strong an inductive action



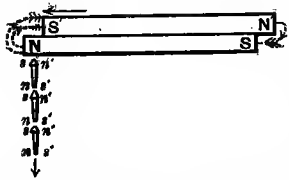
BALANCING A NEEDLE BETWEEN HARD STEEL AND SOFT IRON.

set up by the magnetism of the needle in the soft iron bar at the greater distance as there was in the steel bar at the shorter distance, on account of the greater magnetic resistance of the latter.

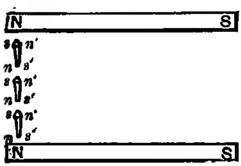
EXPERIMENTS XVII.—**Inductive Effects of Like and Unlike Poles.**—Take a bar magnet and a few soft iron nails. Hang the nails in a chain, one below the other, say from the **N**-pole of

the magnet. Let us suppose that it is strong enough to support a chain of three nails. Now gradually slide along the top of the magnet the **S**-pole of another bar magnet (as illustrated by the accompanying figure), and you find that, one by one, the nails will fall away. The same thing happens if the **N**-pole of the second magnet is brought under the nails, as shown by the next figure. If, however, you bring the **N**-pole of the second magnet above the nails or its **S**-pole below them, you will be able to add a fourth, and possibly a fifth, nail to the chain, as represented by the two following figures. By induction, the **N**-pole of the first magnet polarises the first nail. It in turn magnetises the second nail; and the second, the third; and so on. When the **S**-pole of the second magnet is brought along the top of the first magnet, it tends to induce a **N**-pole in the nails, where already there is a **S**-pole, and a **S**, where there is a **N**. This neutralises so much of the effect of the first magnet, that the weight of the nails causes them to drop off. The very same thing happens when the **N**-pole is brought near the nails from below. When, however, we bring the **N**-pole of the second magnet over the nails, the existing polarity in them is confirmed and strengthened; the force of attraction among themselves and between them and the magnet is increased; and, hence, we can add to the length of the chain.

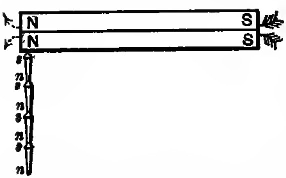
Whilst the two magnets (repre-



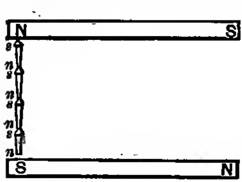
DEMAGNETISING INDUCTIVE EFFECT OF AN UNLIKE POLE.*



DEMAGNETISING INDUCTIVE EFFECT OF A LIKE POLE.*



INCREASED MAGNETISING INDUCTIVE EFFECT OF A LIKE POLE.*



INCREASED MAGNETISING INDUCTIVE EFFECT OF AN UNLIKE POLE.*

* It will be a useful exercise for the student to draw these four figures to a larger scale, and to show by dotted lines and arrows the directions of the magnetic lines of force under the different circumstances in accordance with previous explanations.

sented by the third of the last set of figures) are very materially assisting each other's inductive action *on the nails*, they are, at the same time, as it were, fighting against one another. Each **N**-pole, while it is strengthening the polarity of the nails, is weakening the inductive action of the other **N**-pole by tending to convert it into a **S**-pole, or by repelling its lines away from the direction of the nails. This explains why it is, that two magnets placed together with like poles adjacent, will not attract and support twice as long a chain, or as great a weight of nails as one magnet will. It also explains why compound magnets (referred to and illustrated in Lecture II.) are not so strong as the sum of the strengths of their separate plates.

Polarity Reversed or Consequent Poles produced by Induction.—If a pole of a strong magnet be gradually brought up to a *like* pole of a weaker magnet, *repulsion* will take place when they are within a certain distance of each other; but if the distance is diminished so that the two magnets are close together, *attraction* will result; from the fact, that the natural polarity of the weaker magnet has been reversed. This is sure to be the case whenever a weak magnetic needle is suddenly placed in a strong magnetic field, wherein the lines of force are flowing in the opposite direction to those *through* the needle, and the needle from any cause is not free to instantly turn round so as to set its polarity in the same direction as that of the field. Great care should, therefore, be taken not to subject magnets or needles to this reversing action. It may happen, however, that the weaker needle or magnet, especially if it be a long one, instead of having its polarity entirely reversed, has merely an *unlike* pole induced at the end nearer the stronger magnet, while still retaining its former unlike pole at the further end. In this case, unlike poles, or what are termed *consequent* poles, are sure to be found existing somewhere along its length. In either case, before the magnet or needle can be effectively made use of again for experimental purposes it must be freshly and properly magnetised.

Lecture VI.—Questions.

1. What is the magnetic condition of a bar of soft iron held horizontally above, and parallel to, a permanent magnet of the same size, resting horizontally on a table? Give a sketch indicating the polarity of the bar and the direction of the lines of force.

2. Near a ball of perfectly annealed soft iron, the north end of a strong steel magnet is placed. What is the action of the magnet upon the ball? What change occurs in the ball when the magnet is withdrawn? And what occurs when the south pole of the magnet, instead of the north, is placed near the ball? Illustrate your answers by diagrams.

3. A compass-needle and a straight strip of soft iron of the same length as the compass-needle are fastened together so as to be in contact with each other at both ends. Will the force which tends to make the combination point north and south be the same as that which would act on the compass-needle alone? Give reasons for answer. (S. and A. Exam., 1887.)

4. A rod of iron and a rod of steel are stroked in succession with one of the poles of a bar magnet. How do the iron and steel rods respectively affect a compass-needle when brought near it? (S. and A. Exam., 1889.)

5. Two bars of soft iron are so placed to the east and west of the north pole of a compass-needle that the needle still points north and south. If the iron to the east of the needle be replaced by a bar of hard steel of exactly the same size and shape as itself, will the direction in which the magnet points be altered? If so, in which direction will it move, and why? (S. and A. Exam., 1888.)

6. When a piece of soft iron is attracted by a magnet, the iron is said to be magnetised, so that the attraction really takes place between two magnets, the original one and the one produced by magnetisation. What proof can you give of the truth of this statement?

7. A bar magnet is laid on a table with its N-pole projecting over the edge. A soft iron ball clings to the under-side of the projecting end. State and explain what happens when the S-pole of a second magnet is brought above and near to the N-pole of the first. Give sketches.

8. Two similar rods of very soft iron have each of them a long thread fastened to one end, by which they hang vertically side by side. On bringing near the iron rods, from below, one pole of a strong bar magnet, the rods separate from each other. Explain this. (S. and A. Exam., 1885.)

9. A dozen sewing-needles are hung in a bunch by threads through their eyes. How will they behave when hung over the pole of a strong magnet?

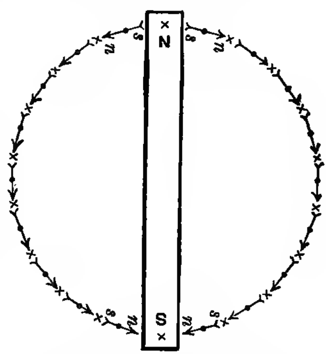
10. A long magnet and a piece of soft iron of the same size and shape are placed parallel to each other underneath a sheet of paper upon which iron filings are strewed. How will the filings arrange themselves? (S. and A. Exam. 1891.)

11. A bar magnet is laid upon a table, and a soft iron bar of about the same length as the magnet is hung horizontally just above it by a flexible string. What will be the effect (*if any*) on the soft iron bar if a second bar magnet be laid on the table and brought near the first, at right angles to it, and with its north-seeking pole pointing to the middle of the first magnet? (S. and A. Exam., 1885.) Give sketches and explain your ideas of the actions which take place, by drawing the lines of force as they will occur before, and when, the second bar magnet is brought near the first.

LECTURE VII.

CONTENTS.—The Earth Regarded as a Magnet—Geographical and Magnetic Poles and Meridians—True Polarity of the Earth—Declination or Variation—Inclination or Dip—Earth's Magnetic Axis and Equator—Questions.

EXPERIMENTS XVIII.—**The Earth Regarded as a Magnet.**—Lay a strong bar magnet on a pile of books or on a flat board raised above the level of the table, and carry a compass-needle round the magnet on a level with it, exactly in the manner described and illustrated in Lecture III. Or, hang the bar magnet up by one end in a vertical position and pass a dipping-needle round it, following the outlying lines of force. You will find that in whatever position the needle is placed one of its poles will invariably tend to point towards one pole of the magnet, and its other pole to the other pole of the magnet. In fact, the magnetic axis of the needle in each experiment always forms a tangent to the bar magnet's curved lines of force at the position where the needle happens to come to rest.



DIPPING-NEEDLE TANGENTIAL TO MAGNET'S CURVED LINES OF FORCE.

Precisely the same effect is observed if a dipping-needle be carried round anywhere on the surface of the Earth from pole to pole as illustrated by the figure on the next page. This proves that the Earth possesses magnetic force, and that a magnetic field surrounds it on all sides. It is due in a large measure to the directive action of the Earth's magnetism upon the mariner's compass-needle that the navigator is enabled to steer his course from place to place when beyond the sight of land, and that the African explorer finds his way across the "Dark Continent." We may therefore fairly assume for the purposes of elementary explanation that the Earth

acts magnetically as if it had a great magnet inside it, and we consequently illustrate it here as if such were the case. For a more advanced and exact understanding of all the phenomena attending the Earth's magnetism other views of the case have to be considered and discussed, but an explanation of these views would be out of place at present. We shall therefore now proceed to explain different terms and particulars relating to "*the Earth as a magnet*" by aid of a few diagrams and experiments.

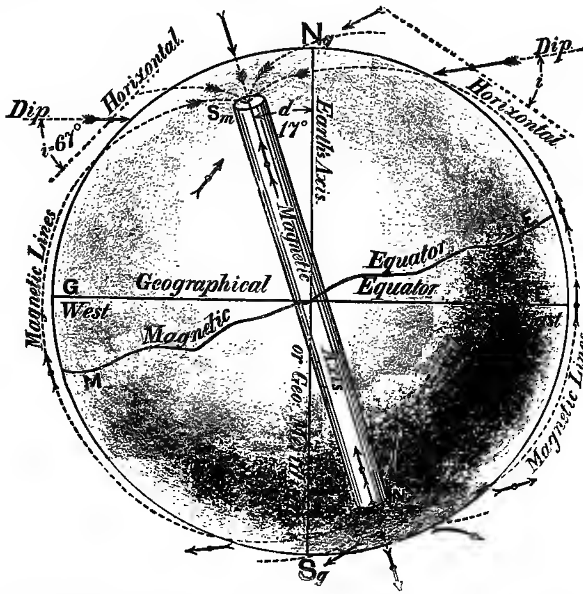


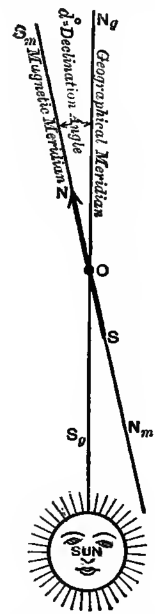
DIAGRAM OF THE EARTH AS AN IMAGINARY MAGNET, ETC.

INDEX TO FIGURE.

N*g*	means	North geographical pole.
S*g*	"	South geographical pole.
N*m*	"	North magnetic pole (true).
S*m*	"	South magnetic pole (true).
N*g* to S*g*	"	Earth's axis (if a straight line).
" "	"	A geographical meridian (if a circumferential line).
N*m* to S*m*	"	Magnetic axis (if a straight line).
" "	"	A magnetic meridian (if a circumferential line).
GE	"	Geographical equator (circumferential line).
ME	"	Magnetic equator (circumferential line).
d	"	Declination or variation angle (=17° at London, 1889).
i	"	Inclination or dip angle (=67° at London, 1889).

EXPERIMENTS XIX.—**Geographical and Magnetic Poles and Meridians.**—Note the direction of the sun at mid-day* and lay down a straight line on a level board or table; such that, if produced or extended into a great vertical plane it would exactly bisect the sun. Mark the end of this line towards the sun, S*g* (for South geographical direction), the nearer end N*g* (for North geographical direction), and then take a point, O, midway between them. Upon this line place a compass-needle with its centre exactly over the point, O. After the needle has come to rest under the influence of the Earth's magnetism, mark on the board the position of the needle's **N** and **S** poles.† Remove the needle and draw a straight line through O, joining N and S, and extend this line in each direction to S*m*, and to N*m*, as shown by the accompanying figure.

An extended vertical plane passing in the direction, ON*g*, would pass through the North geographical pole of the Earth, and if extended in the opposite direction, OS*g*, it would pass through the South geograph-



FINDING THE GEOGRAPHICAL AND MAGNETIC MERIDIANS, AND THE DECLINATION.

* According to Greenwich mean time, the sun is due south at mid-day four times every year (about April 14, June 14, Sept. 1, and Dec. 25), consequently if Greenwich time be adopted it will be necessary to consult the "Nautical Almanac" in order to find how many minutes before or after mid-day the SUN is exactly south, and the observation to be correct must be taken accordingly. By solar time the sun is due south every solar mid-day. Another plan, often adopted by sailors, of finding the geographical and magnetic meridians, and from these the declination or variation angle, is to observe the direction of the North Star, then the direction of the magnetic axis of the mariner's compass, and to note the angle between them; making the necessary plus or minus allowance shown by the "Nautical Almanac" for the time and place that the observed direction of the North Star may be to the East or to the West of the true direction of the geographical North Pole.

† It may happen that the poles of the compass-needle are not situated exactly in the straight line joining the ends of the needle. In order to check this possible error, the needle should be fitted with two centres, thus, —×→ so as to admit of turning it upside down. If any difference should now occur in the positions of **N** and **S**, then take the mean positions between the first and last observation for the poles of the magnetic axis of the needle.

ical pole; consequently, the line, Sg—Ng, lies in a *Geographical Meridian*; for—

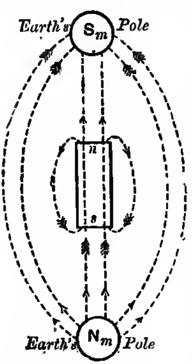
BY DEFINITION.—*A Geographical Meridian is an imaginary line drawn on the Earth's surface in the plane which passes through the geographical poles of the Earth and a given place.*

Again, an extended vertical plane passing in the direction, ON or OSm, may be assumed to pass through the *true** "Magnetic South Pole" of the Earth; and if in the direction, OS, or ONm, to pass through the *true* "Magnetic North Pole" of the Earth; consequently, the magnetic axis of the compass-needle, SN, or the line Nm—Sm lies in a MAGNETIC MERIDIAN; for by—

DEFINITION.—*A Magnetic Meridian may be taken as an imaginary line drawn on the Earth's surface in the plane which passes through the magnetic poles of the Earth and a given place; or more accurately as a line in the vertical plane containing the magnetic axis of a compass-needle at a given place.*

Declination or Variation.—Referring again to the two last figures, you observe that the line, Ng—Sg, coincides with the Geographical Meridian of the position, O (or place of observation), and that the line, Nm—Sm, coincides with the Magnetic Meridian

* **True Polarity of the Earth.**—The student must carefully observe and remember that since *unlike poles attract* and *like poles repel each other*, the **N**-pole of the magnetic needle can only be *attracted* by a **S**-pole, of another magnet, and the **S**-pole of the needle by a **N**-pole. He must therefore regard and always mark the polarity of the Earth by **S**m, for the *true south* magnetic pole situated in the *Northern* hemisphere, and by **N**m, for the *true North* magnetic pole situated in the *Southern* hemisphere. Considerable ambiguity and vexatious explanations will be avoided if he at first adopts, and then adheres to, this notation and view of the case. The accompanying small figure (in addition to the previous larger "Diagram of the Earth as an Imaginary Magnet") will still further impress this upon him. The figure illustrates a bar magnet (n, s) upon the Earth's surface, and the true **N**m and **S**m poles of the Earth with the lines of force as they *actually* circulate *through* the magnet, round the same, and to the Earth's poles, as well as the Earth's *external* field (or surface Earth's lines between the **N**m and **S**m poles of the Earth). The lines which pass *through* the bar magnet are in the *same direction* as the Earth's lines, but the external field lines of the bar magnet circulate or act in the *opposite direction* to the Earth's field lines. We have in the text used the words "may be assumed to pass through the true magnetic poles," because, in *reality*, the magnetism of the Earth is so irregular that we cannot say that the meridian would pass through them in all cases.

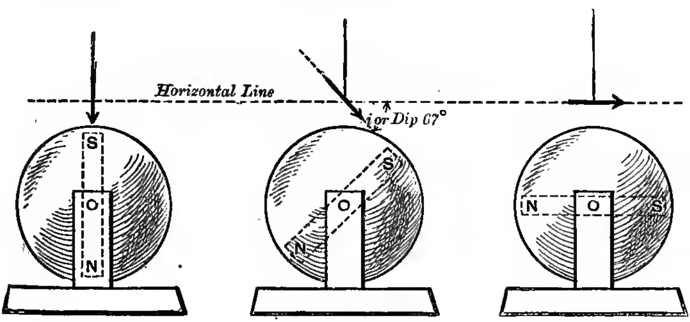


TRUE POLARITY OF THE EARTH, AND OF A MAGNET ON ITS SURFACE.

of the same place. These two lines make an angle, $d°$, with each other, and this angle is termed the Declination or Variation angle for that place. Hence we have the following—

DEFINITION.—*The Declination of a place is the value of the angle in degrees between the magnetic meridian and the geographical meridian of that place.* The Declination is termed (E.) *Easterly* or (W.) *Westerly* Declination, according as the magnetic meridian lies to the East or to the West of the geographical meridian when looking from the north pole of the compass towards the Northern Hemisphere. The declination is different for different places on the Earth's surface; and it also varies from time to time. Thus, at London, in 1800 it was 24° 6′ W.; in 1880, 18° 40′ W.; by 1888 it fell to 17° 40′ W., and is still decreasing; at Sydney, in 1880, it was 9° 30′ E.; and at Glasgow at present, in 1889, it is about 21° W.

EXPERIMENTS XX. — **Inclination or Dip.** — Take a large wooden ball (10″ or 12″ in diameter—an old globe will do very well) pivoted on a wooden stand. Fix a cylindrical magnet 8″ or 10″ long inside it and diametrically opposite to the axis upon which the ball rotates. See that the poles of this magnet are equidistant from the surface of the ball. Let this ball represent the Earth. Now suspend a dipping-needle above the centre of the ball, as shown by the following fignres :—



AT POLES. AT LONDON. AT MAGNETIC EQUATOR.

WOODEN MODEL WITH BAR MAGNET TO REPRESENT THE EARTH.

Then turn the ball round into each of the above positions and watch the effect upon the dipping-needle.

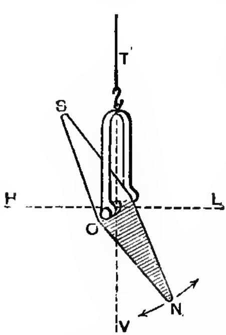
1. When the bar magnet is vertical with its **S**-pole (representing the *true*, Sm, or South Magnetic pole of the Earth) next the needle, the latter hangs perpendicular with its N-pole pointing downwards. Upon turning the ball half round, the needle again

assumes a vertical position, but its **S**-pole is downwards, being attracted by the, Nm, pole of the magnet. These two positions represent what would take place if you could take a dipping-needle to places on the Earth's surface fairly opposite the magnetic poles of the Earth.

2. Turn the ball round through an angle so as to approximate roughly to the angle which a line drawn from London to the centre of the Earth would make with the Earth's magnetic axis, and observe that the needle dips or inclines about 67° to the horizon. This represents the inclination of a dipping-needle at Greenwich Observatory.

3. Turn the ball still further round until the magnet lies horizontal. You observe that the needle also becomes horizontal or parallel with the bar magnet. This represents the position of a dipping-needle at the Earth's magnetic equator. Now refer back to the two first figures in this Lecture, and observe the several positions of the small dipping and compass needles (——>) drawn around and upon those diagrams; and you cannot fail to imagine the actual condition of magnetism as it emanates from and encompasses the Earth.

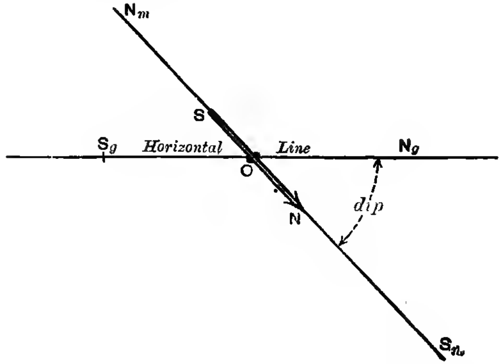
From observations made with dipping-needles at different latitudes it has been proved that the magnetic poles are situated some distance inward from the surface of the Earth. Also (as may be illustrated by the wooden model), the nearer a compass is brought to the magnetic poles the less sensitive does it become as a director of position; in fact, if it was taken right opposite the poles it would have no directive action, for it would simply tend to stand vertically, like the needle in the first case in the last experiment. Again, on the contrary, the nearer a compass-needle is taken to the equator the more free and sensitive is its action.



EXPERIMENT XXI.—Take a flat board (a drawing-board will do very well), and set it up vertically in the plane of the magnetic meridian. Draw a horizontal or level line, SgONg, along the middle of the board, and hang from a copper nail by a thread without twist, or hold up, a dipping-needle* so that its axis is just opposite the point, O. When the needle comes to rest, mark on the board the positions of the poles N and S of the needle, and, upon removing

* Like that in the above figure. See Appendix to "Magnetism" for how to make and use a Laboratory Dipping-needle.

the needle, draw the line, N*m*OS*m*, through the points, S, O, and N. The needle (as previously explained) takes up a tangential



FINDING THE DIP, OR INCLINATION ANGLE.

position to the magnetic curved lines of force at the place; and, since it is free to lie exactly in the magnetic meridian, the angle, N*g*OS*m* (formed between the magnetic axis of the needle and the horizontal line), constitutes what is termed the *Inclination* or *Dip Angle.*

DEFINITION.—*The Inclination or Dip at a place is the angle in degrees between the magnetic axis of a dipping-needle (free to move in the plane of the magnetic meridian) and a horizontal line in the same plane.*

The angle of inclination (i), or the dip, is gradually decreasing at present in this country; for, as registered at London, in 1800 it was = 72° 8′ N., in 1868 = 68° 2′ N., and in 1888 = 67° 25′. In Glasgow at present it is nearly 72°.

The Earth's Magnetic Axis and Equator (see second figure in this Lecture).—Like a bar magnet, the Earth has both a magnetic axis and a magnetic equator.

DEFINITIONS.—*The* MAGNETIC AXIS *of the Earth is the straight line which joins its magnetic poles.*

The MAGNETIC EQUATOR *is an imaginary irregular line drawn round the Earth, and joining all places where the dipping-needle lies horizontal when placed with its magnetic axis in the plane of a magnetic meridian.*

Local circumstances, such as great deposits of iron with other magnetic ores, local magnets of various kinds, and magnetic storms, considerably affect the regularity of the magnetic equator

line, as well as the declination and the inclination at different places on the Earth's surface. Charts giving the average local horizontal intensity of the Earth's magnetism, the local declination and inclination at different important parts of the Earth (with separate curved lines connecting, (1) places which have the same intensity, (2) the same declination, (3) the same inclination), are procurable by mariners and others, to whom such knowledge is of importance. Daily and continuous most accurate observations are made at Greenwich and Kew Observatories, as well as at several other similar stations of every variation and circumstance connected with the Earth's magnetism.

LECTURE VII.—QUESTIONS.

1. Sketch a section of the Earth through its magnetic poles, showing the true polarity, magnetic meridian, and magnetic equator; also geographical meridian, geographical equator, magnetic axis, and magnetic equator.

2. What is the meaning of the term "geographical meridian"? What is the meaning of "magnetic meridian"? What name is given to the angle between the two meridians, and what is its present value at London?

3. Explain concisely and clearly why the magnetic pole of the Earth, situated in the Northern Hemisphere, is termed a true South pole? If you called it a North pole, then what would you call the pole of a compass-needle which pointed towards the North, and why?

4. You are asked to illustrate the declination and the inclination of the magnetic needle; how will you proceed? Point out the *full* analogy between the Earth's action and that of a bar magnet.

5. How does the position of a "dipping-needle" change when it is taken from London (*a*) towards the North pole, or (*b*) towards the Equator? (S. and A. Exam., 1885.)

6. What is meant by saying that the magnetic dip at London is 67° 30′? State in general terms at what places on the Earth's surface the magnetic dip is least. (S. and A. Exam., 1888.)

7. How do (1) a dipping-needle, (2) a compass-needle, behave at the magnetic poles of the Earth? (S. and A. Exam., 1889.)

8. If a compass were carried round the Earth's equator, would it point in the same direction at all places? If not, state, as nearly as you can, what changes would be observed in its behaviour during the journey. (S. and A. Exam., 1887.)

9. If you wish to support a uniform bar magnet horizontally on a pivot, how is it that the pivot must be placed nearer to one end than to the other? To which end must it be nearer in this country?

10. A bar magnet suspended horizontally sets in the magnetic meridian. Supposing a second bar magnet to be suspended by the side of the first, how will they act upon each other? Make your answer clear by a diagram.

11. A large soft iron rod lies on a table in the magnetic meridian, and a dipping needle is placed at some distance and at about the same level, (1) due south, (2) due north of it. How will the magnitude of the angle of dip be affected in each case? (Neglect any inductive action between the needle and the bar.) (S. and A. Exam. 1890.)

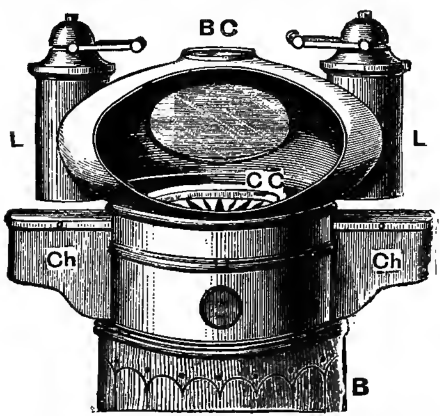
12. A compass needle is deflected 15° from the meridian, when a bar magnet is placed on the table some distance away. Will the deflection be altered if the poles of the magnet are connected by a bent iron rod? Give reasons. (S. and A. Exam. 1890.)

13. Given a magnet and the means of suspending it. How will you determine (1) the magnetic meridian, (2) in which direction *North* lies? It is assumed that you do not know which end of your magnet is a north and which a south pole. (S. and A. Exam. 1891.)

LECTURE VIII.

CONTENTS.—The Mariner's Compass—Magnetisation by the Inductive Effect of the Earth's Magnetism—Magnetisation of Iron and Steel Ships—The Earth's Influence on a Magnet is Directive, but not Translative—A Compass-needle always obeys the Stronger Force—Astatic Pair—Questions.

The Mariner's Compass.—We have more than once referred to this, the oldest and the most useful, application of the magnet. Difficult and dangerous as the navigator's occupation often is, it would be very considerably increased had he not his reliable friend, the compass, to guide him. This fact is now so thoroughly recognised that every registered ship is bound to be fitted with a tested and certified mariner's compass before leaving port. We shall here explain a ship's compass of the simplest kind, leaving a description of Sir William Thomson's improved form to our Advanced Treatise, as it involves the examination of several points somewhat beyond the range of an elementary text-book.



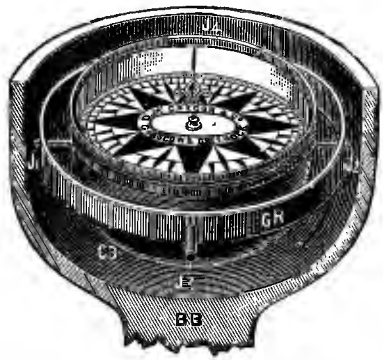
M'GREGOR'S PATENT MARINER'S COMPASS.

INDEX TO FIGURE.

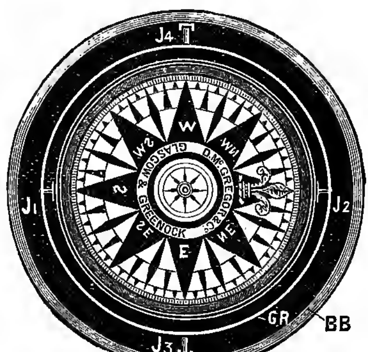
CC represents Compass card.
B represents Binnacle case, inside which the controlling magnets are fixed to compensate for semicircular and heeling errors.
Ch represents Chain boxes where wrought-iron chains are kept to compensate for quadrantal error.
BC represents Binnacle cover.
LL represents Lamps to light up compass card at night.

Referring to the two following figures and explanatory index, you will observe that the instrument consists of a carefully-made magnetic needle, so fastened to the under-side of a light card that

the centre of the needle coincides with the centre of the card, and its magnetic axis is fairly in line with the north and south points of the same, the north pole of the needle being next the north point or "head" of the card. The centre of the needle is fitted with a small ∧ cup of agate or sapphire stone, in order to minimise the friction and avoid rusting between it and the fine pointed steel support upon which it rests and turns. The combined card and needle are accurately balanced on this steel point, which is centrally fixed to the inside of a brass or copper bowl. The bowl is provided with a glass cover to protect the card from damp and dust, without concealing from view the various degrees and indications printed upon the surface of the card. The bowl is not rigidly fixed to its binnacle or case, but is supported on a "gimbal," which permits the bowl and card to maintain a level position when the ship pitches or rolls. The gimbal ring has two bearings diametrically opposite each other, which carry the outstanding knife edges or round journals fixed to the bowl, and at right angles to these are two other journals, which fit into the bearings secured to the binnacle bowl.



SECTIONAL ELEVATION THROUGH BINNACLE BOWL.



PLAN OF COMPASS CARD* AND BOWLS.

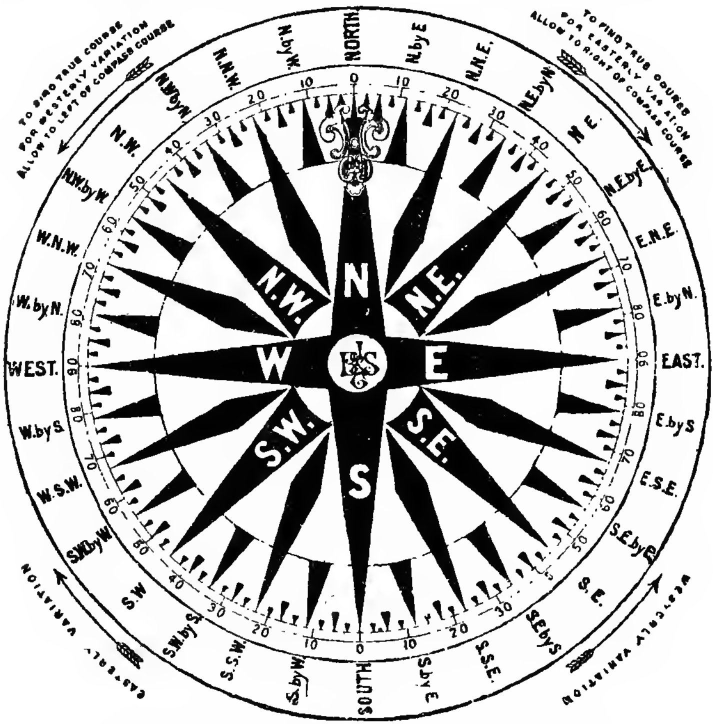
M'GREGOR'S ORDINARY COMPASS.

INDEX TO ABOVE FIGURES.

CB	represents	Compass Bowl and Card.
J_1J_2	"	" Journals.
GR	"	Gimbal Ring.
J_3J_4	"	" Journals.
BB	"	Binnacle Bowl.
❙	"	Lubber Line (top fig.).

* The compass card is shown on the plan (by mistake) as turned through 90° to the right of its position on the sectional elevation.

The steering compass is placed in front of the "wheel," so that the "man at the wheel" may easily see the compass card, which is divided off into thirty-two "points," as illustrated by the following figure. When he wishes to steer any particular course by compass he turns the helm so that the desired point on the compass card is fairly opposite to the vertical black line (technically



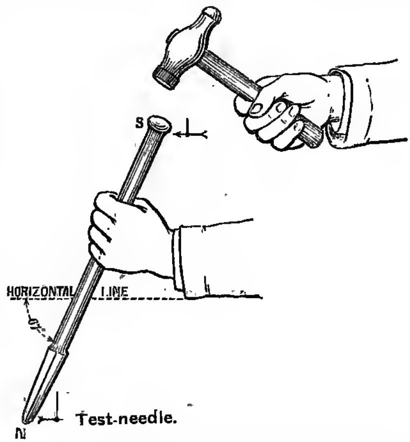
Messrs. Brown & Son's Mariner's Compass Card.

termed the "lubber line"), which is drawn on the forward inside of the bowl, in line with the direction of the ship's motion.

In order to make the mariner's compass a really useful and reliable guide, every ship which makes long voyages should be provided with a chart showing the latest declination or variation at various places on the Earth's surface. The declination has to be added to, or subtracted from, the ship's true course before giving

the steersman the compass course. For Example,—If you wish to make a true North (geographical) course, and the declination at the position of the ship at the time is say 20° W., then the steering course will be 20° E.; or in nautical language you steer exactly North 20° East, or roughly NNE. (North-North-East), more accurately NNE. ¼ N. (North-North-East by ¼ point North). If you had steered North by compass card, the ship's course would have been N. 20° W., or you would have gone continuously 20° to the westward of the intended course. So you see with what watchful care the captain of a vessel has to guard against errors liable to occur through a misapplication of declination. There are other local errors to be guarded against, which will be referred to shortly.

EXPERIMENTS XXII.—**Magnetisation by the Inductive Effect of the Earth's Magnetism.**—Another very conclusive proof that the Earth acts as a magnet is found in the fact that iron or steel bars when they lie in a northerly and southerly direction for some time become magnetised, more especially if they are subjected to vibration. To illustrate this, take a bar of *unmagnetised* steel or hard iron (an ordinary poker will do very well), and hold it level with its length pointing east and west. Test its ends by means of an ordinary compass-needle, and you find that it exhibits no polarity, each end equally showing a slight attraction indifferently for either end of the needle. Now hold it in the magnetic meridian and at the angle of dip for the place you are situated in (say 67° at London, or 72° at Glasgow), as shown by the figure, and hit it several smart blows on the head with a hammer or mallet. Again test it by the needle, and you find that the point has had a north pole induced in it, for it repels the N-pole of the needle, and the head has had a S-pole induced in it, for it repels the S-pole of the needle. Finally hold the bar or poker about level in an east and west direction as at first, and hit it hard several times. Test it now by



EARTH'S MAGNETISM INDUCING POLARITY IN A POKER OR STEEL BAR

the needle, and (unless it was composed of very hard steel) the whole of the magnetism will have disappeared from it. When held in the second position, the bar was fairly in line with the magnetic lines of force of the Earth, and the Earth's polarity induced opposite poles in it, the blows which you gave it merely facilitating the molecules turning round to obey the directive action of the inductive force of the Earth's magnetism. When in the last position, there was the least possible chance of the Earth's force acting inductively upon the molecules of the bar, so that your blows relieved the inter-molecular tension and permitted the polarity of the molecules to become short circuited and self-sufficing amongst themselves in a similar manner to the steel filings when shaken in the glass tube (as illustrated and explained at the beginning of Lecture IV.).

Take a compass-needle to any place where iron or steel has been racked for some time in a vertical position, or to the iron railings surrounding a house or graveyard, and you will find, in this country, that the lower ends of the bars are all N-poles, and the upper ends S-poles, for the reason that the lower ends point towards the true south magnetic pole of the Earth. Of course their magnetism will not be quite so strong as if they had pointed directly in line with the Earth's magnetic force, and, in the case of railings, if they happen to have horizontal bars of iron securing their top and bottom ends, these bars will act as keepers and prevent your observing the full extent of free magnetism which they would exhibit if not so fastened.

Magnetism of Iron and Steel Ships.—It may safely be said that every iron and steel ship is a huge floating magnet.

First, when a ship is being built, the hammering and riveting to which she is subjected naturally assists the magnetic inductive action of the Earth's magnetism in producing sub-permanent magnetism in the harder and steely particles of her frames and plates. This effect is all the greater if the "ways" upon which she is built lie north and south. When the ship is sent to sea some of this magnetism may be knocked out of her, due to buffeting the waves, especially if the direction of the ship's head is on a course exactly opposite to that upon which she lay when being built. Still, there is always a certain amount of the originally induced sub-permanent magnetism left, and this produces what has been termed the "*semicircular*" *error* of the compass, or an error felt most when the ship is on a **N**, **E**, **S**, or **W** course. This error is approximately cancelled by fixing a permanent magnet or magnets to the deck, or in the binnacle below the compass, in a line with the keel, so that the polarity of the magnet is opposite to the polarity of the ship. But neither the

magnetism of the ship nor that of the counteracting magnets is constant, and, consequently, navigators require to be continually on the watch for any serious alteration of this error.

Second, when a ship is afloat, the Earth's magnetism induces magnetism in her softer particles of iron or steel, and so produces what has been termed the "*quadrantal*" *error* of the compass, or an error most observable when the ship is on an **NE**, **SE**, **SW**, or **NW** course. This error is approximately cancelled by placing masses of soft iron or magnets athwartships, in a line with, and on each side of, the compass.

Third, there is another error, termed the "*heeling*" *error*, due to the heeling or rolling of the vessel, which is approximately corrected by placing magnets directly underneath the compass in a vertical position.

Fourth, there is the error due to carrying an iron or steel cargo, which may be termed the "*cargo*" *error*. In Telegraph steamers, which have several tanks for holding iron or steel-sheathed submarine cable, this error is very observable and very variable, since the cable is being more or less continually altered in quantity or position, due to paying it out, or picking it up, or shifting it from tank to tank.

Fifth, in steamers which are fitted with the electric light, more especially if fitted upon the "single-wire system"—*i.e.*, with the hull of the ship forming a return circuit for the electric currents—great care and caution has to be observed that the wires are so run and the dynamos so placed that the magnetism arising from their currents and poles does not affect the mariner's compasses.*

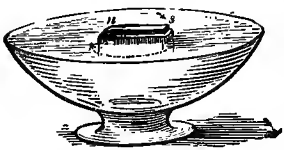
All these five kinds of local errors *combined*, form what sailors term the *deviation* of the compass, and the deviation combined with the *declination* forms the *total error* of the compass. The deviation error may act with, or against, the declination of the place, according to circumstances or the course the ship is steering; and, consequently, before a new ship sets out upon a voyage she is taken to some retired and convenient spot—such as the Gareloch, on the Clyde, for Clyde-built ships—and has her compasses adjusted by a competent and authorised compass adjuster. A Table of the deviation errors of the ship's standard compass† is given by

* In the steamer *Bombay* electrically fitted out in Glasgow under the author's supervision, he noticed a maximum error of 9° in the steering compass, and he had to get double wires run wherever the leads came near to the compasses before the error became inappreciable. Sir William Thomson drew particular attention to this kind of error in a paper read by him upon this subject before the Institution of Electrical Engineers in May 1889.—See *Proceedings* of this Institution.

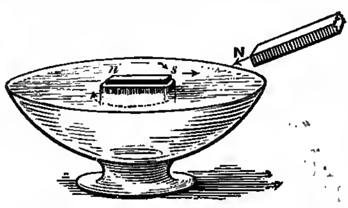
† The standard compass should be a specially well-made compass, fitted

him to the captain before the ship starts on her voyage; but (as has already been pointed out) the circumstances affecting the mariner's compass are so variable that this Table is only true for the place and condition of affairs where and when the ship was swung for compass adjustment. He has, therefore, to avail himself of every convenient opportunity of taking observations of the sun, or the north star, or some well-known headland, in order that he may guard against making mistakes in his navigation.

EXPERIMENTS XXIII.—**The Earth's Influence on a Magnet is Directive, but not Translative.**—The statement is often made that the Earth's effect upon a pivoted or suspended needle is merely *directive*, and is not *translative*. A simple experiment will make the meaning of this clear to you. Float a very small, light magnet on a cork in a basin of water, and place it pointing east and west. Immediately on being released, the cork with its magnet swings round as if on a pivot, and comes to rest with the needle in the magnetic meridian; but neither cork nor needle moves towards the north or towards the south. The *direction* changes, but not the *position*. The Earth's true magnetic south pole is, at the same time, attracting the north and repelling the south pole of the needle; but, seeing that the attractive effect is acting at a shorter distance than is the repulsive effect, the student might expect to find the needle moving as a whole towards the former pole. The poles of the Earth are, however, so far away, that the short distance between the poles of the needle ceases to be of any account when compared with their distances from the Earth's poles. Thus there are forces of attraction, and of



MAGNET ON CORK IN BASIN OF WATER TURNED ROUND BY EARTH'S FORCE ONLY.



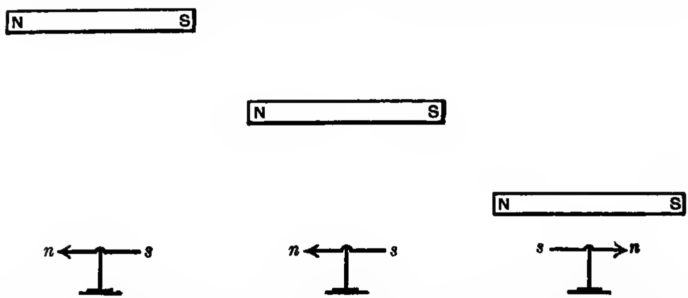
MAGNET ON CORK IN BASIN OF WATER TURNED AND ATTRACTED TOWARDS THE BAR MAGNET.

with all the latest improvements for observing, and, if need be, balancing, the several local errors, or so placed upon an elevated position (such as the top of a wooden pole or mast) that it is practically beyond the local field of the ship's magnetism. This compass is sometimes termed the pilot compass, and is used by the captain and officers as a standard or reference compass, whereby the readings of the ordinary and commoner steering compasses may be checked.

repulsion, acting on the needle at the same time, and at practically the same distance; but as these forces are equal and opposite to each other, the needle, as a whole, is neither attracted nor repelled.

If, however, we bring the pole of a magnet up towards the needle at such a distance that the length of the latter is considerable *as compared with the distance between them*, we shall find that the needle will be both *directed* and *attracted*.

Experiment XXIV.—**A Compass-needle always obeys the Stronger Force.**—Place a small compass-needle on the table, and hold above the needle, and parallel with it, a bar magnet, the poles of which point in the same direction as those of the needle. At first hold the magnet at such a distance that it does not apparently affect the lie of the needle, as shown by the first case in the accompanying figure. Now bring it down slowly, and



Needle beyond the Reach of Bar Magnet's Field of Force.

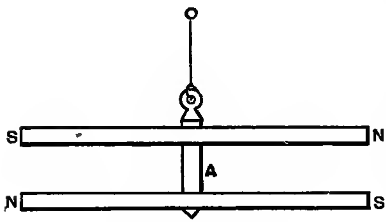
Astatic Position. Earth's Magnetism and Bar Magnet Balance each other.

Needle under the Influence of the Stronger Force.

when at a certain distance the needle will be observed to waver, and jerk about. If the magnet be fixed here, it will be found that the needle will set or stand still in any position that is given to it. If the magnet is brought down still further, the needle will turn sharply half round, and come to rest with its poles as shown by the third case in the above figure. In the first position, the magnet was so far away that very few of its lines of force passed through the needle, and, consequently, the latter was not appreciably affected. As it approached closer, more lines of force passed through the needle, until, in position number two, it was able just to counteract the directive force of the Earth's magnetism. As a consequence, the needle was free to set in any position. Brought nearer still, the influence of the magnet

overcame that of the Earth, and the needle, obeying the stronger of the directive forces, turned round and came to rest with its S-pole towards the N-pole of the magnet.

Astatic Pair.—With the magnet in the second position, the needle was said to be *astatic* (Greek, ἀ and ἵστημι, I stand) because it was found *standing still*, or resting, in whatever position it was mechanically placed. If, then, two magnets be taken equal in length and in strength of pole, and fixed together by a stout piece of wire or other rigid connection, with their magnetic axes parallel and their similar poles pointing opposite ways, they will form what is variously termed an *astatic pair*, *astatic combination*, or *astatic needles*. For if such a combination is suspended by the middle, as shown by the figure, so as to be free to move in a horizontal plane, the two magnets satisfy or neutralise one another. The Earth's attractive force on the N-pole of one needle is exactly counterbalanced by its repelling force on the S-pole of the other needle, and consequently there is no directive force to cause the combination to set in any particular position. We shall have occasion afterwards not only to show that it is practically impossible to make a perfectly-astatic pair, but also of explaining how this arrangement of two needles when combined with one or with two coils of wire forms a most useful and reliable kind of sensitive galvanometer for indicating the presence and direction as well as for measuring the strength of electric currents.



ASTATIC NEEDLES.

Lecture VIII.—Questions.

1. Sketch and describe the simplest form of mariner's compass, and give an "Index of Parts," stating of what each part is made, and why?

2. Why are iron and steel ships said to be magnets?

3. What are the several kinds of errors to which a mariner's compass is liable? What are the causes which produce these several errors?

4. Explain in your own words why the mariner's compass has sometimes a steel magnet or magnets fixed near it, on to the deck in front of it, and at each side of it. Why are lumps of soft iron sometimes fixed athwartships on each side of the standard compass? What do you mean by the standard compass?

5. If a long bar of very soft iron is held upright, how is it that its upper end repels the south-seeking end of a compass-needle, and that its lower end repels the north-seeking end of a compass-needle? What would be the precise effect of hitting the end of a bar of steel when held in the magnetic meridian, and at the angle of dip (in this country)? What would be the effect if the bar was held level east and west, and then hammered?

6. Two equal bars of steel, after having been equally magnetised, are kept for some years in a vertical position, one (*a*) with its south-seeking pole upwards, the other (*b*) with its north-seeking pole upwards. The bars are so far apart that they do not act on one another; which of the two bars would you expect to find had kept its magnetism better, and why? (S. and A. Exam., 1886.)

7. A bar of soft iron AB is placed horizontally east and west, the east end A being about 4 inches to the west of the north-seeking pole of a compass-needle. The end A being fixed, B is raised until the bar is vertical. How is the needle affected by the bar when in its original and final positions? (S. and A. Exam., 1889.)

8. A small magnet is placed upon a flat cork which floats in a basin of water, and it is fastened to the cork with a little wax. Describe and explain the behaviour of the magnet (1) when under the influence of the Earth's magnetism alone, (2) when an artificial steel magnet is brought near to it. (S. and A. Exam., 1887.)

9. It is sometimes said that the Earth has no tendency to impart to a magnetic needle a motion of translation, but that it has under certain circumstances a tendency to impress upon it a motion of rotation. What is the meaning of these statements?

10. A strong bar magnet is placed on a table with its axis lying in the magnetic meridian, and with its north-seeking pole towards the north. State in what direction a compass-needle points (1) when placed immediately over the centre of the bar magnet, (2) when gradually raised vertically upwards.

N.B.—The compass-needle can only turn about its pivot in a horizontal plane. (S. and A. Exam., 1888.)

11. How would you construct an astatic needle out of a uniformly magnetised strip of watch-spring, which you are allowed to bend or break as you please? (S. and A. Exam., 1887.)

12. Two equal and equally-magnetised bar magnets are fastened together

at their centres at right angles to each other, so as to form an equal-armed cross. How will the cross set itself when balanced at the middle upon a point?

13. An astatic combination of two magnets is injured so that the magnets are at right angles instead of parallel to each other. If it be suspended as usual, what position will it assume with regard to the magnetic meridian? Illustrate your answer with a diagram showing the forces which act upon the magnets. (S. and A. Exam., 1888.)

14. The beam of a balance is made of soft iron. When it is placed at right angles to the magnetic meridian, two equal weights placed in the opposite pans just balance. Will the weights still appear to be equal when the balance is turned so that the beam swings in the magnetic meridian? Give reasons, with sketches, for your answer. (S. and A. Exam. 1889.)

15. A piece of steel wire, bent so as to form two sides of a square, is magnetised in such a way that each of its free ends is a North pole, and the bend a South pole. When placed upon a cork floating in water, how will it set? (S. and A. Exam. 1890.)

16. A rod of iron, AB, held vertical with the end B downwards, is smartly tapped with a mallet. When turned into a horizontal position and brought near to a compass needle, the end B repels the North pole of the needle at a distance of four inches, but attracts it when the distance is reduced to one inch. Explain this. (S. and A. Exam. 1890.)

17. A tall iron mast is situated a little in front of the compass in a wooden ship. Explain the nature of the compass error when the ship is sailing in an easterly direction (1) in the northern, (2) in the southern hemisphere. (S. and A. Exam. 1891.)

18. A rod of iron when brought near to a compass needle attracts one pole and repels the other. How will you ascertain whether its magnetism is permanent or is due to temporary induction from the earth? (S. and A. Exam. 1891.)

N.B.—Along with this Appendix the more advanced student should refer to a paper read by W. H. Preece, F.R.S. before the British Association Meeting, 1890, on Experiments with different brands of Steel and their Magnetic Intensities. Also to Prof. S. P. Thompson's Cantor Lectures on the "Electro Magnet," delivered before the Society of Arts in 1890.

APPENDIX.

PRACTICAL NOTES ON MAKING EXPERIMENTAL APPARATUS FOR STUDYING MAGNETISM.

Preliminary Note.—Every student of Magnetism and Electricity has naturally a great desire to make and to experiment with the apparatus illustrated in his text-book, or shown and described to him by his Teacher in the Lecture-Room. This desire is often thwarted by the idea that the materials and necessary tools are beyond his means; and even should he have these at his command, unless he is a trained mechanician, or has a natural aptitude for such work, he probably becomes disheartened by a failure in his very first attempt to make some simple piece of apparatus—or, having made it, to get the desired results from it.

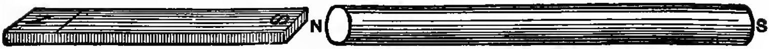
Now, the materials and tools are of the cheapest and simplest kind, and may be procured gradually, as he requires them, from any optician and a tool shop or second-hand shop that deals in hardware implements. Failure in making the apparatus, or in getting the desired results from it when made, generally arises from not following some prescribed method which has been found successful by others.

In The Glasgow and West of Scotland Technical College, the Author has conducted for some years Practical Electrical Instrument-Making Classes, where the Day Students are each provided with a bench and drawer to hold their own tools, and they have in addition the use of the College engine, dynamos, lathes, grindstones, and drilling-machine, &c. Under such circumstances, he finds that the Electrical Students not only take a very deep interest in their practical work, but that they obtain a much more thorough and lasting knowledge of the leading principles of Magnetism and Electricity than can be gained from merely attending lectures. He also finds that Elementary Evening-Class Science and Art Students, who make apparatus and experiments at home for the purpose of more thoroughly understanding the Lectures and the Class questions, are thus better prepared for the Advanced Class and the Electrical Engineering Laboratory than if they merely studied text-books

The following notes are but a few examples of what the Elementary or First-year Students are in the habit of making in the Magnetism Section. Further examples of Electrical Apparatus will be given under the Appendixes to the sections on Voltaic and Frictional Electricity. If these notes are appreciated, they will be extended in future editions.

To Make a Permanent Magnet.—(1) Read carefully over the following instructions, and then make a full-size or scale drawing of the

shape and size of magnet required. For private experiments a convenient size is $6'' \times \frac{1}{2}'' \times \frac{1}{4}''$ for a bar magnet, but for most lecture-room experiments it should be not less than $12'' \times 1'' \times \frac{3}{8}''$, or if cylindrical, $12'' \times \frac{3}{4}''$ diameter.

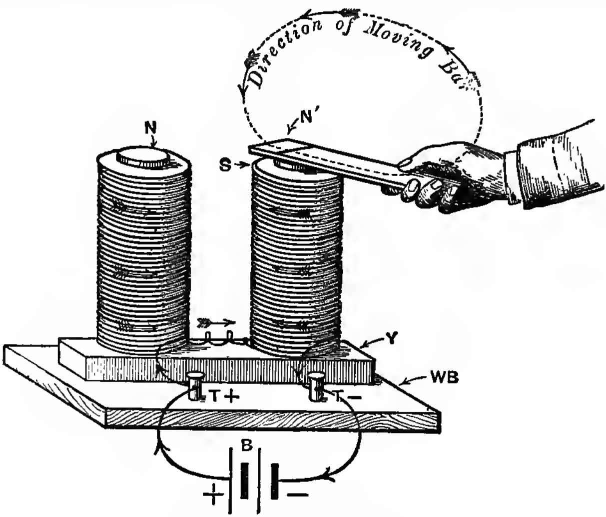


BAR MAGNETS.

(2) Procure a piece of good close-grained, rolled steel that has not been heated since it was first made, of the shape and size required.*

(3) Trim the ends neat and square by a file, and put on a file-mark (as shown in the above figure), or type one end with the letter N.

(4) Put the steel into a clean bright fire, and let it become gradually heated until it has reached a moderately bright red; take it out by the tongs, and dip it level and *sideways* into a can or dish of cold water, moving it about until it is quite cold, thus tempering it glass-hard. Care must be taken that the steel is never made a bright red or white-hot, and that it is uniformly red all over its length and on all sides just before being put into the water. A coke-fire is naturally better than a coal-fire, but best of all for heating the steel is one of Fletcher's Metallurgical Laboratory Gas-Ovens.



MAGNETISING BAR MAGNET.

The hardening must be done promptly and, if possible, at a first heat, for we find that steel will not make such a good magnet if heated a second or third time with the view of getting better results from it.

(5) Magnetise the tempered bar with the **N** or marked end as a North

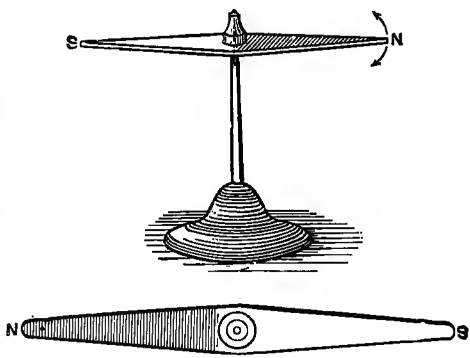
* Messrs. Spagnoletti and Crookes, Adelaide Works, Uxbridge Road, London, make a speciality of supplying the best magnetisable steel at very moderate prices.

pole by any one or other of the processes described in Lecture I., remembering, however, that if you have a good electro-magnet and strong battery or dynamo-current at your disposal, this method will yield the best results; and do not rest satisfied unless your magnet will easily lift another piece of hard steel of its own weight, or from three to four times its own weight of soft wrought iron.

(6) With two such magnets, a sheet of paper, and some paraffine wax, &c., you are in a position to perform the experiments illustrated and explained in Lecture III., *re* making magnetic curves, &c.

To Make a Compass-needle and Stand.—(1) Read over the following instructions, make a full-size drawing of side view and plan, and procure the materials required.

(2) Chisel or turn the base from a piece of mahogany, or other bit of hard wood, and after boring a small hole fair through the centre to fit a large darning-needle, fix the latter tightly and vertically into the hole with the pointed end upwards.



COMPASS-NEEDLE.

(3) Upon a piece of thin strip steel $4'' \times \frac{1}{2}'' \times \frac{1}{32}''$, or a piece of strong clock-spring or crinoline steel, describe the outline plan of the needle, keeping the ends rounded, unless the needle should be required for taking deflection readings on a graduated card. The advantage of rounded ends when the needle is simply used for indicating the presence or polarity of magnets or currents is, that for the same length of needle you get more mass, and, therefore, greater magnetic turning effect; moreover, junior students are liable to break the fine points.

(4) Soften the strip by first putting it into the fire or into the flame of a Bunsen burner or spirit-lamp until it gets dull red, and then letting it cool slowly in fire-ash. Bore a tapered hole, about $\frac{3}{16}''$ or $\frac{1}{4}''$ diameter, at the centre of the steel, and with a chisel or a metal-shears cut the needle roughly into shape, just leaving sufficient margin to file or grind it true to the drawing.

(5) Make a glass or hard brass, Λ, centre to fit the hole in the needle. A glass centre is constructed from thin soft English-made glass tube, about $\frac{1}{4}''$ outside diameter, by taking a piece of it about 6" or 8" in length, and holding the middle of it in the flame of a Bunsen burner, or blow-pipe, or spirit-lamp, and turning it round and round between the fingers and thumb of each hand (applied to each end of the tube) until it gets uniformly soft at the part held in the flame; then suddenly pulling fair and straight with each hand in a line with the axis of the glass tube until it is separated into

two pieces with conical ends. Now take one of these pieces in the right hand and turn the fine conical point in the flame until a neat rounded end is formed thereat Try the cone into the hole in the needle, and mark on the glass close to the under-side of the needle. Take it out, and with a Δ file cut a groove fair round the tube. Put the groove line into the flame, and applying a little pressure to the point of the cone, break it off from the rest of the tube. Grind the rough edge of the base of the cone on the file until it is smooth.

A brass, Λ, centre may be turned in the lathe from a piece of hard brass rod. This requires some skill in brass-turning to make a neat, light, deeply bored centre.

(6) Temper the needle in the manner described in the previous and the next set of notes.

(7) Fix the, Λ, centre evenly into the hole with a little melted shellac, or balsam-cement, or glue.

(8) Magnetise the needle by one or other of the methods explained in Lecture I.

(9) Now try the needle upon the pointed support, and you will probably find that the **N**-end dips. You will consequently have to grind a little off that end until it balances evenly, and again magnetise it to saturation.

(10) Paint the **N**-end red with vermilion paint, and the **S**-end blue with Prussian blue.

You can now perform all the experiments mentioned in Lectures III., V., &c., wherein the compass-needle bears a part in testing the polarity of magnets, &c.

To Make a Dipping-needle and Dip Circle.—A simple and cheap form of this instructive piece of apparatus may be easily made by students themselves, as explained by the accompanying figure and description. The form illustrated below will be found sufficiently delicate for the laboratory work of junior students, or for class lecture purposes.

Operations.—(1) Read carefully over the following instructions, and then make a full-size drawing of the apparatus similar to the above figures.* Mark thereon the more important dimensions, make out a list with sizes, of the various things required, and procure them.

(2) From a well-seasoned plank of yellow pine 1" thick, make the base, B, and the upright board, UB. Secure them together truly at right angles to each other by three or four *brass* screws. If of large dimensions it may be necessary to affix four neat *brass* (L) corner pieces between, B, and, UB, about 2" from the ends of the latter.

(3) From hard wood (mahogany or birch) shape out the horizontal bracket, HB, and turn or chisel the back central nipple for, UB. Fit neat *brass* pinching screws into the parts indicated by, PS, on the above sketch.

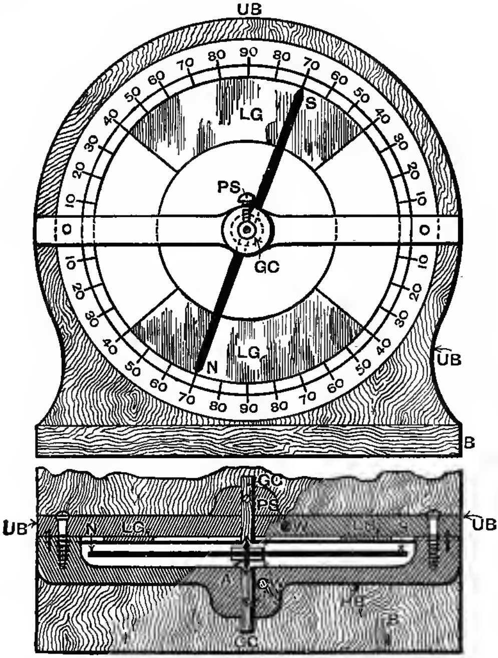
(4) Glue on the hard-wood centre piece to the back of, UB. Dowel pin, and then screw on, HB, with brass wire and brass screws.

(5) Procure two pieces of soft English glass rod about 6" long by $\frac{1}{4}$" diameter, and indent sharp, **V**, grooved centres in one end of each by holding the rods in turn with the left hand in the flame of a blowpipe or Bunsen burner, whilst you press fairly and evenly forward in a line with the axis of the glass rod a heated fine steel pricker, draw point, or stout darning-needle.

(6) Level the base board, B, by an ordinary spirit-level, and by means of

* The next drawing to a scale of $1\frac{1}{2}$" to the foot is a suitable size for lecture purposes.

a surface-gauge or a set-square mark off centres on the front and back of, HB, and, UB, all on a level line. Then bore out a true, fair, and level hole right through to fit the shanks of the glass centre rods, GC, and insert them into the holes.



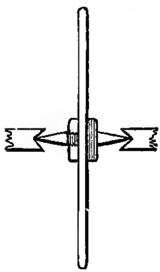
DIPPING-NEEDLE AND DIP CIRCLE.

Note to Figure.—In the plan of the above figure the needle has been intentionally drawn full length, as if it lay horizontal, to show that it clears the insides of the horizontal bracket.

Index to Side View and Plan.

NS	represents	**N** and **S** poles of the dip needle.
A	,,	Axis of needle.
CW	,,	Central washers to needle.
GC	,,	Glass, **V**, centres.
PS	,,	Pinching screws.
B	,,	Base (of wood).
UB	,,	Upright board.
HB	,,	Horizontal bracket (of hard wood or brass).
0 to 90	,,	Scale on cardboard or on paper.
LG	,,	Looking-glass (to assist in avoiding *parallax* error).

(7) *Making the Dipping-needle.*—(*a*) Procure a piece of good magnetisable steel strip 8" to 12" long, according to the size of the dip circle, $\frac{3}{8}$" to $\frac{1}{2}$" broad, and about $\frac{1}{32}$" thick. Special steel strip may be easily secured from the magnet makers, or a strong clock-spring or the blade of a worn-out metal saw may be ground and dressed up to suit. (*b*) Shape the < > ends by a chipping-chisel or metal-shears, and by grinding. Soften the middle, and bore a hole truly at right angles to the strip to fit *tightly* a darning-needle about 1" along from the point. Grind the other end of this darning-needle to a correspondingly fine, true smooth point, and force it into the hole in the steel strip. (c) Insert this axle, A, between the glass centres, GC, and revolve the dipping-needle so as to test whether the axis is *truly* at right angles to the strip, and whether the glass centres are fair and level with each other. If the dipping-needle should be "off the truth," or square, as it is technically termed, you may have to widen the hole and press tight on to, A, two ebonite or cardboard washers, CW, and fix them to, NS, with balsam or glue, taking care that these washers dry to the dipping-needle with the needle truly at right angles to its axis.* If the glass centres are not fair and level to each other, turn one or both of them round until they are so, mark the position opposite to the pinching screws, PS, and grind a short flat piece on each of them, so that the points of these pinching screws may always naturally fix the glass centres in the adjusted position. (*d*) Now balance the dipping-needle very accurately by grinding off a little from one end or the other until, when set horizontal, it will remain so, although the axle may be perfectly free between its centres. (*e*) Next take the needle out, and carefully temper the ends *glass hard* until within an inch or so of the centre. There is considerable liability of such a length of thin steel strip becoming warped or twisted in this tempering process, but if you take a length of soft fine iron wire and bind it round the strip from the middle to the end before heating it to a dull red, and then dip the strip *vertically* into the cold water, you should succeed without bending the needle. (*f*) Finally, magnetise the dipping-needle by one or other of the methods described in Lecture I. If you have not got an electro-magnet or a long solenoid capable of taking in the whole length of the needle, then you should use the *divided touch* method.



(8) From a piece of stout white cardboard (fully $\frac{1}{16}$" thick) cut out the complete circle for the scale, with indents, so as to let it be curved and slipped in between the inside ends of, HB. Cut out a central hole the size of, GC, and two quadrants or sectors or segments to fit two pieces of looking-glass, LG, of the same thickness as the cardboard. Glue on the cardboard and the two pieces of looking-glass.

(9) Thoroughly clean the points of the axle and the V centres, and replace the dipping-needle between the glass centres so that it is perfectly free to move round with a minimum of lateral movement. Stick on a weighted cork to the, N-end of the needle, turn the plane of, UB, east and west magnetically, carefully level the base with a spirit-level, and look fair upon the needle until its reflection in the looking-glass is exactly hidden. Mark the position where the point of the S-end comes to rest on the card. Mark this point 90°. Remove the weighted cork, and see if the

* Some mechanicians prefer to screw the axis and fit on two brass washers, as shown by the small figure above, but this plan is rather too difficult a job for an ordinary student.

needle again comes to rest exactly as before. Mark in the same way as before a point 90° opposite the **N**-end of the needle.

(10) Remove the needle (and, if necessary, the horizontal bracket), and with one point of a pair of compasses placed in the back, **V**, centre describe the various circles, and divide them off neatly, as shown by the above sketch, but with *tenths* of degrees added in the full-size card. Students who are not skilled or tidy may find that they have so soiled the cardboard that they would prefer to draw the circles upon a sheet of paper, and afterwards paste the same upon the cardboard. They must be careful, however, that the two 90° coincide with the vertical positions just found under operation (9) for the needle, when it is at right angles to the magnetic meridian, and that the paper circle is finally fixed dead true with the back, **V**, centre.

Necessary Observations to Find Out the Mean Angle of Dip for the Place and Needle.—(1) Again place the apparatus so that the needle hangs vertical—*i.e.*, with **N** and **S** exactly opposite the lower and upper 90° respectively. When the base has been carefully levelled, run a pencil mark round the edge of the rectangular base. Now turn the base round through 90°, level the base, and take a reading of the needle. This tells us roughly the angle of dip, for the plane of the needle's motion is now in the *magnetic meridian*. Suppose the reading to have been 70°. If we accepted this as the true dip, we assume three improbable things about the needle—

(*a*) That its magnetic axis coincides with the line joining the < > points.

(*b*) That its centre of mass coincides with its centre of motion both in regard to its breadth and its length.

(*c*) That there is no frictional error or no friction between the axle and the glass centre bearings.

We have, therefore, to take the mean of eight sets of readings (of which the following series is an example) before we can say with any degree of accuracy what is the true dip.

Inclination Test, made in The Electrical Engineering Laboratory of The Glasgow and West of Scotland Technical College, by A. H. Allen, Oct. 1889.

1st.—To find the position at right angles to the Magnetic Meridian :—

Circle facing *North* Pointer on horizontal scale at	100°.	Needle at 90°.
" " *South* " " "	136°.3	" "
Mean position of pointer " "	118°.15	" "

Circle then turned through 90°, pointer at 28°.15 on scale.

2nd.—To find angle of dip :—

Marked end North seeking.

	N-pole Reading.	S-pole Reading.	Mean.
1. Circle facing *West*, Face of Needle towards Circle	73°.10	72°.50	72°.80
2. " " " " from "	79°.52	79°.52	79°.52
3. " " *East*, " " "	73°.25	72°.60	72°.92
4. " " " " towards "	79°.70	79°.70	79°.70

Marked end South-seeking.

5. Circle facing *West*, Face of Needle towards Circle	67°.80	68°.15	67°.95
6. " " " " from "	53°.75	53°.15	53°.45
7. " " *East* " " "	70°.95	70°.95	70°.95
8. " " " " towards "	58°.15	57°.55	57°.85

Mean of the Means of all readings **69°.39**

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LECTURE XIX.

LECTURE XX.

APPENDIX TO PART II.

ELEMENTARY MANUAL

OF

MAGNETISM AND ELECTRICITY.

PART II.

ELECTRO-MAGNETISM.

LECTURE IX.

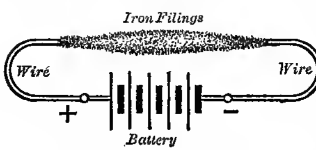
CONTENTS.—Electro-Magnetism—Supply of Current for our Experiments may be Derived from Batteries or Dynamos—Magnetic Field of a Straight Current—Direction of the Magnetic Field of a Straight Current—Direction of Currents in Conducting Wires—Specimen Question and Answer—Questions.

Electro-Magnetism.—Part I. of this Manual was chiefly devoted to illustrating and describing experiments with a view to proving the primary laws of Magnetism and the fundamental principles underlying their practical applications. In Part II. we shall now treat in a similar manner of Electro-Magnetism and Electro-Kinetics or Current Electricity. The study of Electro-Magnetism naturally follows directly after that of Magnetism. For, whenever and wherever an electric current exists, for however short or long a time, a magnetic field is always created along and around the whole path of the current. Moreover, some of the most important practical applications of Magnetism, as in the case of Telegraphy, Telephony, Electric Lighting, &c., necessitate the use of electric currents for their action.

Supply of Current for our Experiments may be Derived from Batteries or Dynamos.—In the first place, we shall take for granted that we can derive Electric Currents from batteries or dynamos without expecting that the student knows anything more about these appliances than the fact that they are sources of electrical energy, from which we can obtain at pleasure any

desired supply of current for the purposes of our experiments. Later on, we shall describe in detail the construction and erection of several forms of batteries and the principles upon which Electric Currents are produced by dynamos. In most of our diagrams we shall adopt the method now commonly employed by practical Electricians of illustrating a Battery by alternating long thin and short thick parallel lines thus, , with the , +, sign to indicate the positive end or terminal where the current leaves, and a , –, sign to indicate where the current returns to this store or source of electrical energy. Also, when the "circuit" or path for a current through a conductor is "closed" or complete, we shall, when necessary, indicate the assumed direction of the current by arrows placed at intervals along the circuit. This simple arrangement will instantly convey considerable information to the student without the necessity for any further explanation in the text. If a dynamo should be substituted for a battery, then the electrician's symbol, , for the same will be used, with , +, and , –, signs to indicate the positive and negative terminals, or where the current leaves and returns to the dynamo.

Magnetic Field of a Straight Current.—Experiment I.—Take a battery, a copper wire, and some soft iron filings. Join the , +, and the , –, ends of the battery by means of the copper wire, and then dip the middle of the wire into the iron filings. We find that the iron filings adhere to the wire and form a cluster round it not unlike what a fresh swarm of bees are in the habit of doing round the first branch of a tree upon which they happen to alight, or like a crowd of ants gathered together upon a sweetened stick. In fact, the filings are attracted and magnetised just as if the wire was surrounded by innumerable magnets with their axes forming tangents to it all along the wire. In Lecture I., we saw that when we dipped a bar magnet into iron filings, the filings adhered to the ends *only*; but in the present experiment we find the filings clinging equally well to the wire whenever we dip it amongst them, and along its *entire* length.

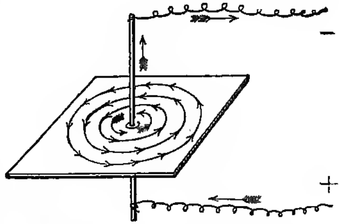


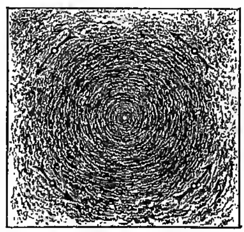
Current in Wire Attracting Iron Filings.

Experiment II.—Take a stout copper wire $\frac{1}{10}$ inch diameter (No. 12 Standard Wire-Gauge), a piece of wood or thick cardboard (8 inches square), a sheet of paraffined paper (like that used in Experiment VII., Lecture III., Part I.), and some iron filings contained in a pepper-pot or muslin bag. Fix the wire centrally

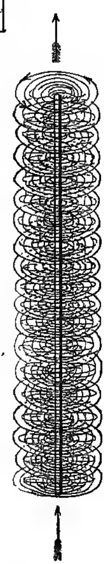
and vertically upwards through the board covered with the paraffined paper, as shown by the first three of the following figures.

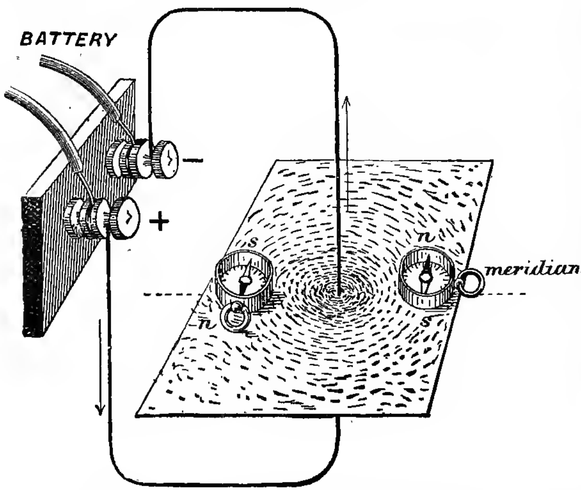
Connect the lower end of this wire to the , +, and the upper end to the , −, pole of a battery or dynamo by flexible wires, and thus pass a strong current (30 to 40 amperes) upwards through the vertical stout copper wire. Then, whilst the current is flowing through the wire, shower down upon the paraffined paper from the pepper-pot or muslin bag (held about two feet above the paper) a quantity of soft iron filings, at the same time tapping the board gently with the other hand, and you will produce a graphic representation of the magnetic field set up by the current in the plane of the paper or at right angles to the direction of the current. In order to fix the filings in their places, you have only to





PLAN OF ABOVE FIGURE.





FIGURES ILLUSTRATING THE MAGNETIC FIELD DUE TO A STRAIGHT CURRENT-CARRYING WIRE.

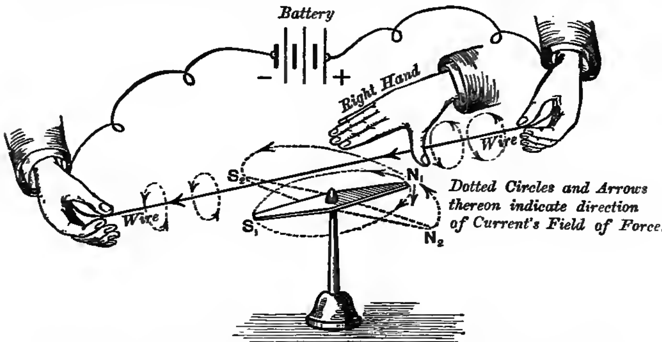
pass a red-hot copper bolt or the flame from a Bunsen burner over (close to but not touching) them, so as to melt the paraffin wax (as explained at page 23, Part I.), when you obtain a diagram like that illustrated by the plan and lower left-hand figures. The right-hand figure is an imaginary picture of the magnetic field surrounding the whole length of the vertical wire, which is supposed to be conveying a current in the direction of the arrows. The magnetic lines of force follow circular paths or swirls around the current-carrying wire, for we observe that the iron filings and small magnetic needles brought within the range of the current's magnetic field are induced to place themselves as tangents to circles of which the wire forms the common centre, whether we pass the current up or down the wire.

Direction of the Magnetic Field of a Straight Current.—We shall now investigate the directions of the magnetic lines of force evoked by a current according as the current flows in one direction or the other.

EXPERIMENT III.—Place a freely-supported horizontal test-needle upon a table. You observe that its magnetic axis takes up a position in a line with the magnetic meridian, and that the **North** pole points northwards. Hold a straight copper wire fair above or below, and parallel to the magnetic axis of the needle. No deflection of the needle is observed; but get some one to connect the ends of the copper wire to the poles of a battery whilst it is in one or other of these positions, and immediately the needle turns round from its natural position to one with its **N**-pole pointing towards the East or towards the West, according to the direction in which the current flows along the wire; *i.e.*, according as one end or the other of the wire is connected to the , +, pole of the battery. This clearly indicates that there is a difference in the direction of the magnetic lines of force produced by the current according as the latter is flowing in one direction or the other. To observe and to remember this precise difference, place the wire and connect it to the battery in the exact manner indicated by the figure on page 83.

You observe that the **N**-pole of the needle turns from you. Now get some one to place his **Right Hand** above the wire with the palm of the hand *towards* the wire, and with the fingers pointing in the same direction as the current is flowing, and ask him to extend his thumb at right angles to his fingers, and consequently at right angles to the direction of the current. You observe that his thumb points in the *same* direction as the **N**-pole of the needle placed *under* the wire. Reverse the direction of the current by connecting the ends of the straight copper wire to the opposite ends of the battery, or reverse the

wire, and again holding it parallel to the magnetic needle, get your assistant to place his **Right Hand** as before (viz., with the palm towards the wire, and with the fingers pointing in the same direction as the current). His outstretched thumb will be found to point in the *same* direction as the **N**-pole of the compass or test needle. Place the wire below the compass-needle and pass the current in *either* direction, and you will find that if the palm of the Right Hand be placed towards and on the opposite side of the wire to the compass-needle, the outstretched thumb will *always* indicate the direction in which the **N**-pole turns. This

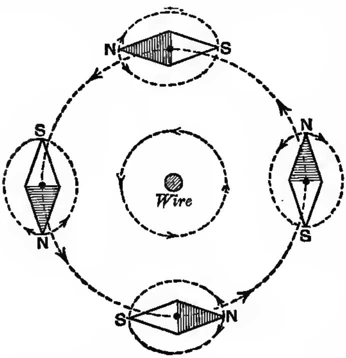


TESTING FOR THE DIRECTION OF THE MAGNETIC FIELD DUE TO THE KNOWN DIRECTION OF CURRENT IN A STRAIGHT WIRE, OR *VICE VERSA*.

rule (devised by the author) is so easily remembered after a few trials that it can never be forgotten, and, moreover, it is far simpler than Ampère's rule or any of the many devices mentioned in other text-books. Besides which, as we shall show later on, it can be applied to ascertaining the polarity of a solenoid, and with a slight modification to Professor Fleming's rule for finding the direction of a current in a Dynamo Generator Armature, or the direction of rotation of an Electric Motor Armature.

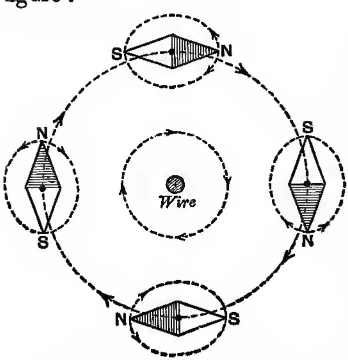
EXPERIMENT IV.—*First,* Take the stiff copper wire and pass it vertically through the centre of the flat horizontal wooden board, as in Experiment II. Connect it to your battery and pass a strong current *upwards* through the wire as before. Whilst the current is flowing place a horizontal test-needle at some little distance from the wire, and move it round the latter. You observe that it *always* lies with its magnetic axis as a tangent to the circle of which the wire forms the centre, and with its **N**-pole directed as indicated by the **Right-Hand Rule**. Now, if you draw a plan of this experiment as illustrated by the accompanying

figure, plotting out the directions of the magnetic lines of force as they naturally flow from and around the test-needle, due to its *own* inherent magnetism, as well as the circular magnetic lines of force due to the current, you cannot help noticing that the direction of the latter is the same as the *needle's own lines through itself.* The needle, therefore, naturally places itself so as to accommodate and assist the magnetic lines of force due to the current.



CURRENT FLOWING UP THROUGH PAPER.

Second, Pass the current downwards through the wire, and immediately your test-needle turns round so as to fulfil the same law. Apply the **Right-Hand** test and plot down a plan of the experiment, when you have the following figure :—



CURRENT FLOWING DOWN THROUGH PAPER.

If we could produce a *Free* **N**-pole unattached to a **S**-pole (which experimentally we cannot do), we should find that this **N**-pole would revolve round the wire in a circle in the direction of the current's magnetic lines of force so long as the current lasted; but seeing that our **N**-pole is unavoidably attached rigidly to a **S**-pole (which is naturally equally impressed in the opposite direction), the axis between them takes up a fixed position tangential to the circular direction of the current's magnetic field.

Hence THE RULE.—*The direction of the magnetic lines due to an electric current is the same as the natural direction of the magnetic lines through the body of a freely-suspended and otherwise unaffected test-needle brought within the range of the current's field.*

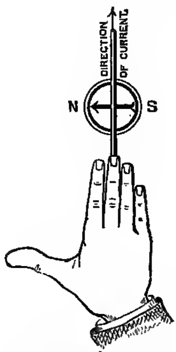
The converse of this rule is also most convenient, for it is very often of great importance to an electrician to know in which direction a current will flow or is flowing from a battery,

dynamo, or other source of electrical energy, without having to feel his way along the whole length of conducting wire to the source.

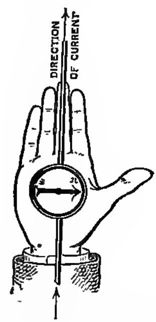
Direction of Currents in Conducting Wires (*Jamieson's Rule*). —EXPERIMENT V.—1. Move the conductor (if possible) into the magnetic meridian.

2. Place a freely-suspended compass-needle below or above the wire. The current will deflect the N-pointing end of the needle to the left or to the right.

3. Place the RIGHT HAND as it were in the wire with the *palm next* to the needle so that the outstretched thumb



RIGHT HAND ABOVE THE CONDUCTOR. NEEDLE BELOW THE CONDUCTOR.



RIGHT HAND BELOW THE CONDUCTOR. NEEDLE ABOVE THE CONDUCTOR.

coincides in direction with the deflected N-pointing pole of needle. Then the current flows along the wire in the direction indicated by the arrows *to* the negative (–) pole of the dynamo or battery.

SPECIMEN QUESTION AND ANSWER.

QUESTION.—A current flows through a telegraph wire between Edinburgh and London, but you do not know whether it comes from Edinburgh or from London. Supposing this knowledge desired, how would you obtain it?

ANSWER.—Since the telegraph wire joining Edinburgh and London is almost in a line with the magnetic meridian, a compass-needle placed close to and *above* the wire would naturally lie parallel to the wire if no current were passing in either direction. Suppose, however, we find that the N-pole of the needle is deflected to the East; then if the Right Hand be

held *under* the wire and needle with the outstretched thumb in a line with the **N**-pole of the needle, this indicates that the current is flowing Northwards, or from London to Edinburgh. If the needle should be deflected to the West, then by a similar proof-test the current must be flowing from Edinburgh to London.

[The student should make two sketches for himself to illustrate this answer to the question.]

Lecture IX.—Questions.

1. A strong current is passed through a straight copper wire, and the wire is then dipped into soft iron filings. What is the result, and what do you infer from it?

2. A strong current is passed through a wire. What is the condition of the medium surrounding the wire? How would you prove your statements by experiments? Give a sketch of how the lines of force arrange themselves in the vicinity of the wire.

3. A strong current is passed *down* a vertical wire. How would you arrange and carry out an experiment whereby you would obtain a permanent record of the configuration of the magnetic field set up around the wire by the current? If a test-needle were brought near and carried round the wire, what position would it take up, and why?

4. State generally how the lines of magnetic force due to an electric current passing through a wire arrange themselves. Illustrate your answer by a sketch of the experiment, in which your Right Hand, aided by a compass-needle, will always enable you to determine their direction.

5. A vertical wire, down which an electric current is flowing, is held (1) due east, (2) due south of a small compass-needle. How is the needle affected in each case? (S. and A. Exam., 1889.) Give two sketches.

6. Two compass-needles are arranged near each other so that both point along the same straight line. A wire connecting the (+) or platinum and (−) or zinc ends of a battery is stretched vertically half-way between the needles. How will the current in the wire affect the needles, and how will the result depend upon whether the (+) or platinum terminal is connected with the upper or lower end of the wire respectively? (S. and A. Exam., 1887.) Give a neat sketch to illustrate each answer.

7. A wire lies east and west (magnetic) immediately over a compass-needle. How is the direction in which the needle points affected when a *strong* current flows through the wire (1) from west to east; (2) from east to west? (S. and A. Exam., 1889.) Give two sketches.

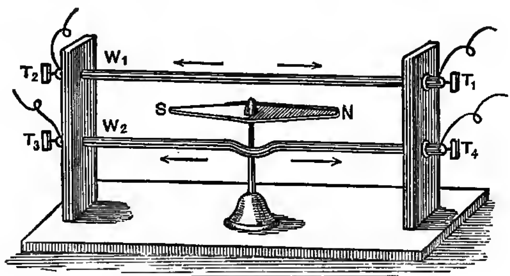
8. A telegraph wire runs north and south along the magnetic meridian. A magnetic needle free to turn in *all* directions is placed *beside* the wire, and on a level with it. How will this needle act when a current is sent through the wire from south to north?

9. A current is flowing through a rigid copper rod. How would you place a small piece of iron wire with respect to it so that the iron may be magnetised in the direction of its length? Assuming the direction of the current, state which end of the iron will be a north pole. (S. and A. Exam., 1891.)

LECTURE X.

Contents.—Simple Apparatus for Studying the Magnetic Action and Direction of Electric Currents—Simple Galvanoscopes, or Simple Vertical and Horizontal Current Detectors—Multipliers or Detector Galvanometers—Specimen Question and Answer—Questions.

Simple Apparatus for Studying the Magnetic Action and the Direction of Electric Currents. — Experiment VI.—Take a piece of apparatus of the following shape and construction,* and place it upon a table, so that the magnetic needle lies parallel with the wires W_1, W_2. *First,* Pass a current from a battery



Apparatus for Testing the Direction of Currents.

through the upper wire, W_1. Observe the direction in which the N-pole of the test-needle turns, and by applying the Right Hand in the manner described by Experiments III. and V. in Lecture IX., determine the direction in which the current flows along the wire W_1, and whether terminal T_1 or T_2 is connected to the , +, pole of the battery. Reverse the position of the battery leading wires and again perform the experiment.

Second, Pass a current through the lower wire, W_2, and then reverse the connecting wires, and in each case determine the direction of the current, and whether terminal T_3 or T_4 is connected to the, +, pole of the battery or other source of electrical energy.

* See Appendix to Part II. for a description of how to make this form of Oersted Apparatus.

In each of these four cases,* when the current is flowing along one or other of the wires, it is evident that the Earth's magnetic force (by its action on the needle's magnetic force) is constantly tending to turn the needle back to the normal position (*i.e.*, in a line with the plane of the magnetic meridian of the place), whilst at the same time the current's magnetic force is deflecting the needle (by its action on the needle's magnetic force) away from the magnetic meridian. The position which the needle ultimately takes up (if the current is kept constant) is the resultant direction due to these two forces acting simultaneously on the magnetic force of the needle. In other words, the needle is deflected from its normal position by an amount depending upon the strength of the current—the Earth's field and the distance of the needle's poles from the wire being considered constant.

EXPERIMENT VII.—Connect terminals T_2 and T_3 by a short copper wire, and terminals T_1 and T_4 to the battery. You now observe that the deflection of the needle is greater than when the current flowed along *only* one of the wires. Apply the Right-Hand test to each of the wires, and thereby determine the direction of the flow of current, and reason out from this, by aid of a sketch, that the directions of the current's magnetic field in W_1 and W_2 both act upon the needle's field so as to assist each other in overcoming the restraining action of the Earth's field. Reverse the battery connecting wires between T_1 and T_4, and again you observe that the deflection is greater than in Experiments VI., but in the opposite direction to that of the above experiment.

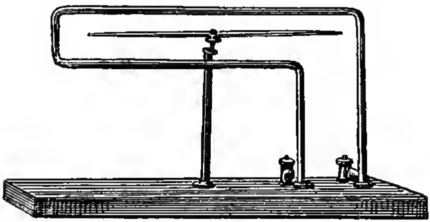
The usual form in which this apparatus is made and supplied by electrical instrument-makers to teachers is illustrated by the accompanying figure. It is termed the "Simple Oersted Apparatus," from the fact that the first published account of the direction in which a magnetic needle turns in obedience to (the magnetic force evoked by) an electric current flowing parallel to the needle's magnetic axis, was described by Oersted of Copenhagen

* The student should make four separate sketches explanatory of each of those four experiments. He should show by dotted lines and arrows—

First, The direction of the Earth's magnetic lines of force.
Second, The direction of the Needle's magnetic lines of force.
Third, The direction of the Current's magnetic lines of force.

By so doing he will most forcibly bring to view the direction in which the N-pole of the needle *must* turn in obedience to direction of the current's magnetic field, &c. If in each case he draws a Right Hand properly placed with respect to the flow of current and the test-needle, he will find that the direction of the outstretched thumb will agree with the direction in which the N-pole turns.

on July 21, 1820.* It consists of a stout copper wire, bent into the form shown, and fixed by its ends to a flat wooden base.



SIMPLE OERSTED APPARATUS.

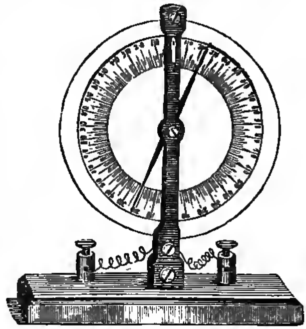
The ends of this bent wire are each connected by a copper strap or wire to a binding screw or terminal also fixed to the same wooden base. A central brass, copper, or wooden pillar, ending in a sharp-pointed steel needle, so supports the horizontal test-needle that it lies midway between the upper and lower horizontal portions of the thick copper wire.

This form of the apparatus does not, however, permit of the following instructive modification of the above experiments, which we shall now describe by aid of the former diagram. Connect terminals T_2 and T_4 by a fairly long copper wire laid along the table, so that a current passing through this wire will not affect the test-needle. See that the needle lies midway between W_1 and W_2, and shift round the apparatus until the wires lie parallel with the magnetic axis of the needle. Now connect terminals T_1 and T_3 to your battery, and you should find that *no* deflection of the needle is produced by the current as it flows from T_1 to T_2, and also in the same direction from T_4 to T_3 (or *vice versâ*, as a whole), for the direction of the current's field around W_1 is contrary in its effect upon the needle's field to that around W_2. These two current fields, therefore, cancel each other's effects upon the needle's field. Should the needle, however, be ever so little nearer to one of the wires (W_1 or W_2) than to the other, then the needle will be deflected by a small amount, due to the difference of the intensity of the two current fields at the position of the needle.

Simple Galvanoscopes or Simple Vertical and Horizontal Current Detectors.—When it is desired to note, for lecture purposes, the direction and, roughly, the relative strengths of strong currents passing in a circuit, we may employ either a vertical or a horizontal galvanoscope or detector of the forms shown by the accompanying figures. The deflections of the needle are read off

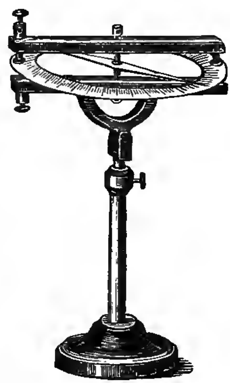
* See *Journal of the Society of Telegraph Engineers* for 1876, pp. 459–469, for a verbatim copy, in Latin, and translation of Professor Oersted's original communication on his discovery of electro-magnetism, dated Copenhagen, 21st July 1820.

upon a graduated scale placed parallel to the plane in which the needle turns, and if made of sufficient size, with the **N**-pole of the needle painted bright red and the **S**-pole bright blue, the action of the needle when under the influence of the current may be clearly observed by a large audience.



Vertical Galvanoscope or Current Detector.

The current in each of these two detectors is conveyed but *once* along the *front* and returns but *once* along the *back* of the needle. As we have already pointed out, the magnetic force exerted by each of these portions of current acts in the same direction upon the needle. If we should, however, require a more sensitive instrument so as to produce considerable deflections of the needle with weaker currents, then all we have to do is to pass the current through an insulated conductor wound many times around the needle.



Horizontal Galvanoscope or Current Detector.

Multipliers or Detector Galvanometers.—Such an instrument as we are about to describe is sometimes called a "Multiplier," since the current's effect upon the needle is thus increased by a certain value depending directly on the number of times that the current circulates round the needle.* It is, however, generally termed a "Detector Galvanometer," the single term Galvanometer being reserved for a still more delicate and accurate instrument for measuring current strength in electro-magnetic measure.

There are many kinds of Galvanometers, such as Astatic, Tangent, Sine, Differential, Ballistic, Sir William Thomson's Mirror, Marine and Graded Galvanometers, Deprez-Darsonval Permanent Magnet and Movable Coil Galvanometer, &c. We shall explain in an elementary manner a few of these instru-

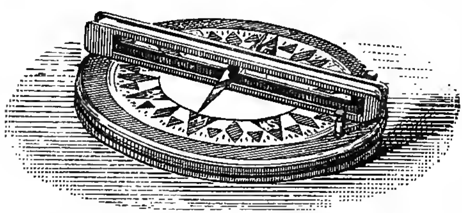
* The magnetic field set up by a current flowing *once* along parallel to the magnetic axis of a freely-suspended needle has just half the moment or turning effect or "torque" upon the needle that the current has if it returns parallel to the magnetic axis on the opposite side of the needle and at the same distance therefrom.

ments in this Manual, and the whole of them fully in our Advanced Text-Book.

The term Galvanometer is derived from the name of an eminent physician of Bologna named Galvani (who first discovered in 1786 the presence of electric currents when experimenting with a frog's leg), and the Greek word μετρον (metron), a measure. Hence—

By Definition.—*A Galvanometer is an instrument for measuring the strength of galvanic (or electric) currents.*

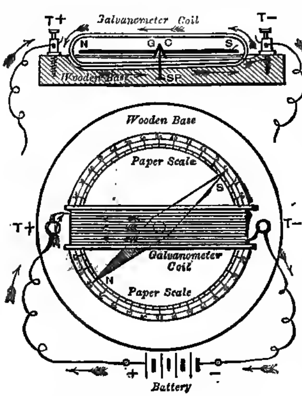
A Detector Galvanometer for class illustration purposes, as usually made and sold by electrical instrument-makers, is shown in perspective by the accompanying figure. It consists of a narrow ▭ shaped wooden bobbin, upon which are wound about 100 turns of No. 20 copper wire insulated with cotton to prevent the current short-circuiting from one turn to another, the two ends of the wire being also connected to terminals fixed into the wooden base.



Detector Galvanometer for Class Illustration.

The card is divided off like the mariner's compass, and the needle is supported upon a fine pin-point between the upper and lower set of layers of insulated conductors.

The two opposite figures show a sectional elevation and plan of the same form of instrument, which students should make for themselves.* Here not only the instrument itself is shown, but also the battery, leading wires, and the direction of the current as it flows through the insulated copper conductor, together with the corresponding direction in which the needle is thereby deflected.

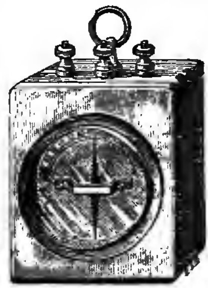


Detector Galvanometer.

In the next figure we have purposely given an outside view of the form which this instrument takes, when supplied to the

* See Appendix to Part II. for index to parts and instructions how to make a Detector Galvanometer.

Telegraph or Telephone Line-Man, or to the Electrical Engineer, as a simple portable detector or rough-and-ready measurer of the presence, direction, and strength of electric currents; for it is advisable that elementary students should be able to recognise at a glance the names and the uses not only of the instruments adopted in the class-room and laboratory, but also of the corresponding instruments employed in the practical applications of electricity. All that the operator has to do in order to use such apparatus is to join the outstanding terminals to the two ends of a circuit (or one end of the leading wire, or the telegraph line to one terminal, and the other terminal to the "Earth" †) in order to detect whether a current is passing or the circuit is complete. If he observes any deflection of the needle (whether to the right or to the left), he thereby understands from a previous test the direction of the current, and from the number of degrees deflection which the needle gives he obtains an approximate idea of the strength of the current.



WOODHOUSE, RAWSON, & CO.'S LINE-MAN'S DETECTOR.*

SPECIMEN QUESTION AND ANSWER.

QUESTION.—Suppose that you were the only person at a very out-of-the-way Telegraph Station, and that you had no proper testing apparatus for localising the position of faults; in fact, nothing but the compass-needle attached to your watch-chain and a length of insulated fine copper wire. Suppose that the single telegraph line between your office and the next one gets broken, and that upon permanently connecting the , +, pole of your battery to the line, and the , —, pole to the earth, you observe that no current passes to line. How would you proceed to find the fault?

ANSWER.—Taking your compass-needle and the insulated copper wire with you, walk or ride alongside of the line for some distance, keeping a sharp look-out for the break. Suppose that you cannot find it in this way. Then bare one end of the fine wire, and

* The three terminals on this instrument are connected up with two sets of coils, the one a thick wire of short length, and the other a finer wire of long length, to suit different lengths of circuits.

† The technical sense in which the word "Earth" is used by electricians will be fully explained later on. Here it may be taken to mean a connection between the galvanometer and a water or gas pipe or a plate sunk in damp soil or in a pond.

climbing one of the telegraph poles, firmly twist that end of the fine wire to the telegraph wire. Returning to the ground, connect the other bared end of the fine wire to the Earth wire which runs down the side of the pole. Now coil round two, or three, fingers of your left hand the middle portion of the fine insulated wire, so as to make up a temporary bobbin or coil of a "Detector Galvanometer." * Place this coil lengthwise in the magnetic meridian with the flat parts horizontal or the plane of the coil vertical, then insert your compass-needle inside the coil. If you get a deflection of the needle, you know that you have not yet reached the fault or break, for your station battery sends a current through the line, and your temporary detector or multiplier to Earth at the pole. You may therefore repeat this simple experiment farther along the line until you get *no* deflection, when you know that you have passed the break, and can consequently cautiously return along the line until you spot the break.

* The coiling of the fine wire into the form of a bobbin is only necessary should you find that no deflection is produced upon your compass-needle when you hold a single length of the connected wire in the magnetic meridian, and close over or under the compass-needle.

LECTURE X.—QUESTIONS.

1. Suppose that you have a galvanic battery, or any other source of electrical energy capable of giving forth electric currents, locked up in a room, and that you have only access to the free ends of the two leading wires connected to the + and − poles of the battery or other generator. Sketch and explain concisely how you would ascertain by aid of a compass-needle which wire was connected to the + pole, and which to the − pole of, say, the battery.

2. Sketch and describe Oersted's simple apparatus for illustrating the magnetic action of a current upon a magnetic needle. Show by arrows upon your sketch, not only the direction of the current, but also the directions of the magnetic lines of force produced by the current in each part of the wire, and the direction of the needle's field before and when deflection takes place. Also show the + and - poles of the battery.

3. A current passing through a long wire is so weak that, when the wire is stretched over and parallel to a suspended magnetic needle, the needle is not perceptibly deflected. Describe and explain any arrangement which would enable you to obtain a movement of the needle by the action of the current. (S. and A. Exam., 1880.)

4. Wires from two separate voltaic batteries are stretched one above the other from north to south (magnetic), and equal currents pass through both wires. If a magnetic needle, free to turn horizontally, but not vertically, is hung half-way between the wires, how will it be affected—

(*a.*) If the currents are in the same direction?

(*b.*) If the currents are in opposite directions? (S. and A. Exam., 1885.)

5. Sketch and describe concisely by an "index of parts," the construction and action of a lecture-room Multiplier or Detector Galvanometer?

6. Sketch and describe by an index a telegraph lineman's vertical "Detector Galvanometer." How, and for what purpose is it used?

7. The conductor of a coil or bobbin of insulated fine wire has become broken, but you cannot feel the break when unwinding it. How would you search for the position of the break with a small compass-needle and a battery?

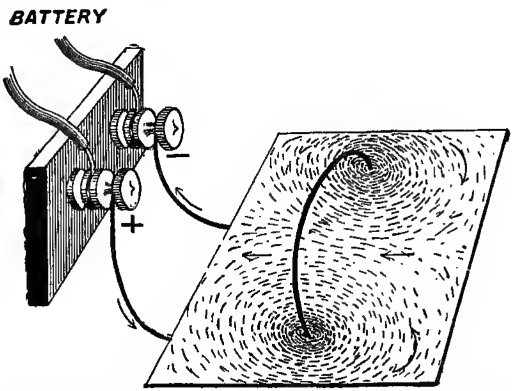
8. Two long wires are placed parallel to each other in the same horizontal plane and in the magnetic meridian. A magnetic needle capable of turning in any direction about its point of suspension is placed exactly half-way between them. How will it behave if the same electric current flows through the easterly wire from south to north and through the westerly wire from north to south? [The action of the earth on the magnetic needle may be neglected.] (S. and A. Exam., 1890.)

LECTURE XI.

CONTENTS.—Magnetic Field and its Direction as Due to a Circular Current—Intensity or Strength of the Magnetic Field at the Centre of a Circular Current—Simple Tangent Galvanometer—Sine Galvanometer—Table of Natural Sines and Tangents—Questions.

Magnetic Field and its Direction as Due to a Circular Current.—EXPERIMENT VIII.—1. Take a stout copper wire about $\frac{1}{10}$ inch in diameter, and bend it into a circle of, say, 10 inches diameter.

2. Fix this wire circle in a vertical position, and in the plane of the magnetic meridian.



GRAPHIC REPRESENTATION, BY AID OF IRON FILINGS, OF THE MAGNETIC FIELD DUE TO A CIRCULAR CURRENT.*

3. Place a piece of stout cardboard or wood covered with paraffin-waxed paper in a horizontal plane containing the horizontal diameter of the wire circle, as shown by the accompanying figure.

* The above figure, as well as those at pages 81 (lower left), 98, 106 (lower two), 107, 108, and the upper one at page 125, have been kindly supplied for this Manual, from Mr. H. D. Wilkinson's "Letters for Learners and Unprofessional Readers," which appeared in the 1889 numbers of *The Electrician*. These excellent articles have since been published in book form.

4. Connect the free ends of the circular wire to the battery or its terminal board, so as to pass a strong current through the wire.

5. Whilst the current is flowing through the wire shower fine soft iron filings upon the paraffined paper.

6. Fix the filings in position whilst the current is flowing by the method explained in Lecture III., Part I.

You observe that the direction of the filings near the centre of the wire circle lie straight along and parallel with its axis, whereas to the right and left of this axis or centre line the filings lie in curves around each side of the wire.

Take a small freely-suspended test-needle,* and whilst the current is flowing through the wire move the needle into different positions inside and outside the wire circle, and you will find that the several positions taken up by the needle corroborate the directions of the magnetic field just obtained by aid of the iron filings. Apply the right-hand test (as explained in Lectures IX. and X.), and it will confirm the direction in which the **N**-pole of the needle turns wherever it is placed with respect to the current-carrying wire.

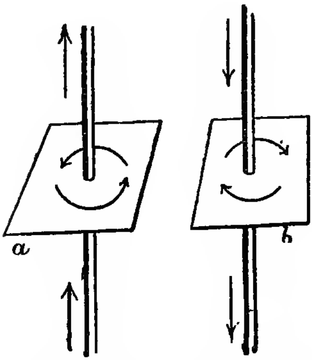
Reverse the direction of the current through the wire, and note the immediate reversal of the direction of the test-needle, wherever it may be placed, within the range of the current's field.

Intensity or Strength of the Magnetic Field at the Centre of a Circular Current.—In the last Lecture we proved that when a current flowed once *above* or *in front of* a magnetic needle, and then returned *below* or *behind* the same, that the strength of the field set up midway between these two currents was double that due to the current through *one* of them, and consequently the deflection of the needle placed midway between these two long and oppositely directed currents was greater than that due to either of these currents acting singly upon the needle. Now, comparing this case with that of a circular current flowing right round a needle, you cannot help observing that the strength of the field, and consequently the deflection of the needle, is still further increased, since *every portion* of the current flowing round the needle tends to set up a magnetic field in the *same direction* at the centre of the circle.

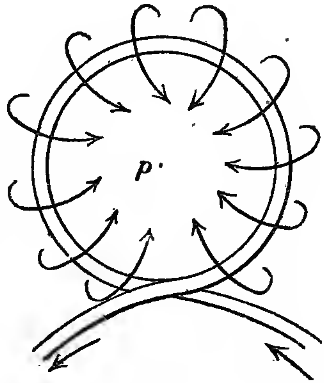
In the following right-hand figure, with the current flowing as depicted, the **N**-pole of a magnet placed in front of the paper, and in the axis of the circle, would be attracted forward from the

* A short piece of magnetised steel wire suspended at its centre by a fine thread, or a double-pivoted test-needle held with its axis parallel to each part of the wire in turn, will do very well.

observer into and forced through the point p, with a force due to the magnetic field set up by *every portion* of the circular current; whereas, in the two left-hand figures, a magnet held midway



MAGNETIC FIELD DUE TO UP AND DOWN STRAIGHT CURRENTS.



MAGNETIC FIELD DUE TO A CIRCULAR CURRENT.

between the straight wires would be impressed forward by the straight portions *only* of the current in each wire. It has been proved by mathematics, and confirmed by experiment, that—

If r = radius of the current-carrying wire circle,

And if $2r$ = the distance between the two *very long* straight wires carrying the *same* strength of current,

Then—

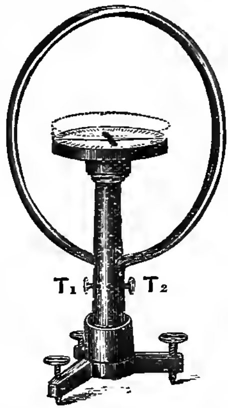
$$\frac{\text{The strength of field at centre of the circular current}}{\text{The strength of field midway between the straight currents}} = \frac{2\pi r^*}{4r} = \frac{6{\cdot}28}{4} = \frac{1{\cdot}57}{1}.$$

Hence, we see that by bending a wire into the circular form and passing a current through it, we obtain an effect upon a magnetic needle placed at the centre of the circle of fully $1\frac{1}{2}$ times the strength that we should obtain by merely passing the same current strength fair *above and below* or fair *in front of and behind* the same needle placed at the same distance therefrom. Consequently we find that accurate and sensitive galvanometers, wherein the needle moves, have their coils of wire made in the circular form. We shall now proceed to describe two forms of galvanometer, whose constancy and accuracy for measuring

* $2\pi r$ is the circumference of a circle whose radius is r, and π is the ratio of the circumference of a circle to its diameter, or $\pi = 3{\cdot}1416$; $\therefore 2\pi = 6{\cdot}2832$, or roughly $= 6{\cdot}28$.

current strengths depend upon their having a circular coil of current-carrying wire.

Simple Tangent Galvanometer.—As will be seen from the accompanying figure, the coil of this instrument consists of a single turn of thick wire or narrow copper ribbon, bent into a circle of ten or more inches in diameter. The free ends of the wire are secured to two terminals, T_1, T_2, fixed to a central round upright piece of dry wood, such as polished mahogany. The lower end of this upright terminates in three stiff arms supported by levelling screws, and the upper end carries a circular case of wood or brass, with a horizontal scale divided into degrees and covered by a plate of glass. In the centre of this circular case is fixed a fine steel point, which supports a very short, thick magnetic needle (one inch or less in length), with a light aluminium or glass pointer cemented at right angles to it by shellac, so that the ends of the pointer extend to the divisions of the graduated scale.



SIMPLE TANGENT GALVANOMETER.

The needle being small and the radius of the coil great, the poles of the needle move in a part of the field (produced by the current flowing round the circle) where its direction and strength are tolerably uniform or constant. Now, by placing the plane of the coil in the magnetic meridian the magnetic axis of the needle will be in the plane of the coil, and consequently the magnetic force produced by the current at the centre of the coil will act at right angles to the polar axis of the needle, and deflect it from this position against the restraining horizontal force of the earth's magnetism. Since this horizontal force of the earth may be considered constant for any particular place (as far as the junior student is concerned), all he has to do is to pass currents of different strengths from his battery through the wire circle by joining the terminals T_1 and T_2 to the + and − battery poles, and to note the deflections of the needle by reading the number of degrees through which the pointer moves to the right or left from its zero or original position.

EXPERIMENT IX.—To ascertain the relative strengths of these currents, look at the following table of tangents * for the tangents

* See the last few pages of Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables" for more complete tables, giving minutes in addition to degrees.

of these angles, when, if d_1 and d_2 represent the deflections in degrees corresponding to the currents c_1 and c_2,

$$\frac{c_1}{c_2} = \frac{\tan d_1}{\tan d_2}$$

$$\text{or } \tan d_1 : \tan d_2 :: c_1 : c_2.$$

That is, the tangents of the angles of deflection are directly proportional to the strengths of the currents flowing through the coil.

Table of Natural Sines * and Tangents.

∠	Sin.	Tan	∠	Sin.	Tan.	∠	Sin.	Tan.	∠	S n.	Tan.	∠	Sin.	Tan.
0°	0000	·0000	18°	3090	·3249	36°	5878	·7265	54°	8090	1·3764	72°	9511	3·0777
1	0175	·0175	19	3256	·3443	37	6018	·7536	55	8192	1·4281	73	9563	3·2709
2	0349	·0349	20	3420	·3640	38	6157	·7813	56	8290	1·4826	74	9613	3·4874
3	0523	·0524	21	3584	·3839	39	6293	·8098	57	8387	1·5399	75	9659	3·7321
4	0698	·0699	22	3746	·4040	40	6428	·8391	58	8480	1·6003	76	9703	4·0108
5	0871	·0875	23	3907	·4245	41	6561	·8693	59	8572	1·6643	77	9744	4·3315
6	1045	·1051	24	4067	·4452	42	6691	·9004	60	8660	1·7321	78	9781	4·7046
7	1219	·1228	25	4226	·4663	43	6820	·9325	61	8746	1·8040	79	9816	5·1446
8	1392	·1405	26	4384	·4877	44	6947	·9657	62	8829	1·8807	80	9848	5·6713
9	1564	·1564	27	4540	·5095	45	7071	1·0000	63	8910	1·9626	81	9877	6·3138
10	1736	·1763	28	4695	·5317	46	7193	1·0355	64	8988	2·0503	82	9903	7·1154
11	1908	·1944	29	4848	·5543	47	7314	1·0724	65	9063	2·1445	83	9925	8·1443
12	2079	·2126	30	5000	·5774	48	7431	1·1106	66	9135	2·2460	84	9945	9·5144
13	2250	·2309	31	5150	·6009	49	7547	1·1504	67	9205	2·3559	85	9962	11·43
14	2419	·2493	32	5299	·6249	50	7660	1·1918	68	9272	2·4751	86	9976	14·30
15	2588	·2679	33	5446	·6494	51	7771	1·2349	69	9339	2·6051	87	9986	19·08
16	2756	·2867	34	5592	·6745	52	7880	1·2799	70	9397	2·7475	88	9994	28·64
17	2924	·3057	35	5736	·7002	53	7986	1·3270	71	9455	2·9042	89	9998	57·29

EXAMPLE.—Let the deflection produced by one battery when joined up with the tangent galvanometer be $d_1 = 17^\circ$, and by another battery $d_2 = 31^\circ$. Then, the currents c_1 and c_2 are *not* proportional to 17° and 31°, but to their respective tangents.

For $\tan d_1 : \tan d_2 :: c_1 : c_2$

or $\tan 17^\circ : \tan 31^\circ :: c_1 : c_2$

$\therefore \quad \cdot 3 : \cdot 6 :: c_1 : c_2$

and consequently $c_2 = c_1 \dfrac{\cdot 6}{\cdot 3} = 2\ c_1,$

or the current is twice as strong in the second case as in the first.

Suppose we so arrange the size of the coil of our tangent galvanometer, &c., that when we get a deflection of 45° the

* Each of the sine values is a decimal quantity.

current shall be one practical unit of current, or, as it is called, one *ampere.* Then, since tan $45^\circ = 1$, the natural tangents of all the other deflections will represent the respective values in amperes, such as in the above case, *e.g.*, tan $17^\circ = \cdot 3$ ampere, tan $31^\circ = \cdot 6$ ampere, and tan $64^\circ = 2$ amperes, and so on, as may be seen from the preceding tables.*

Hence,—

By Definition.—*A tangent galvanometer is one [having a very small magnetic needle, so placed in the field of a coil or coils of large radius that the magnetic field produced by a current in them is approximately uniform at the place where the needle is suspended], wherein the tangents of the angles of deflection are proportional to the strengths of the currents producing the deflections.*

Sine Galvanometer.—One disadvantage of the tangent galvanometer is its want of sensitiveness, due to the necessity of having a coil of large internal radius, in order that it may give accurate results. This implies a comparatively small deflection of the needle for any particular strength of current flowing in the coil. If, however, we mount a coil that it can be turned round upon its vertical axis, so as to follow up the deflected needle until the deflection is a maximum when the coil and the needle are in the same plane, then we may use a much smaller coil and a much longer needle, or the coil as close to the needle as we please, and yet find that the current values of the various

* The student may check his arithmetical results obtained by aid of the "Table of Natural Tangents" in the following manner:—

(1.) Draw a circle upon a sheet of paper of the same diameter as the galvanometer scale.

(2.) Draw any radius to this circle, and consider the point where it touches the circumference as corresponding to the zero or starting-point of the scale.

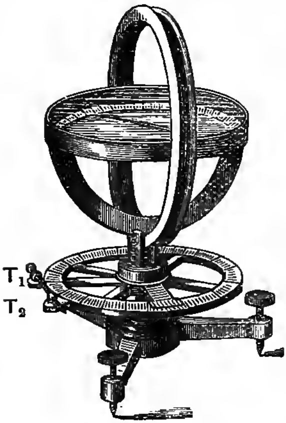
(3.) From this zero point draw a tangent line to the circle.

(4.) Plot out the various angles of deflection of the needle *on the circle* from the zero point, and draw extended radii through each of these points until they cut the tangent line.

(5.) Then measure with any convenient scale or rule *from zero* along the tangent line the several distances to where the several angles of deflection cut the tangent line, and these distances will be directly proportional to the tangents of the angles, and therefore to the currents which produced the same angular deflections of the magnetic needle.

We intentionally avoid treating the student at this stage to the more advanced explanations and formula required for finding by means of a tangent galvanometer the strength of currents in absolute measure, or in practical units of current, viz., amperes (see page 74, Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables"). We also intentionally leave over to our more advanced treatise the method of constructing a scale of tangents, and a description of other arrangements of tangent galvanometers such as those of Gaugain and Helmholtz, which furnish a more uniform field where the needle is poised.

deflections follow a regular law. Such a galvanometer is represented by the accompanying figure, and is termed a Sine Galvanometer, because *the currents passed through the circular coil are proportional to the sines of the angles through which the coil has to be turned from the magnetic meridian in order that a balance may be obtained between the current's field and the earth's field upon the needle when coil and needle are in one plane.*



SINE GALVANOMETER.

This galvanometer (as illustrated) may, of course, be used as a tangent galvanometer by simply fixing the coil in the magnetic meridian, but, as may be inferred from our previous statements, the deflections will not be strictly proportional to the tangents unless the needle is very short. When used as a sine galvanometer, the vertical coil is first fixed in the magnetic meridian, *i.e.*, the coil is moved round until it is strictly parallel to the magnetic axis of the needle. Then the pointer on the lower horizontal scale should stand at zero. When the terminals T_1 and T_2 are attached to the battery, and the current flows through the coil, the magnetic needle is deflected to the right or to the left. The vertical coil is then turned round in the same direction as the needle is deflected, until it fairly overtakes the needle, and again lies parallel with it. The angle through which the coil has been turned is read off on the lower scale, and noted. In this position the current's field has a maximum turning effect upon the needle, and very weak currents may thus be accurately measured by an instrument made out of the simplest and cheapest materials by the student himself.

If $d_1°$ and $d_2°$ be the angles through which the coil has been turned from the meridian position when a balance is obtained due to the respective currents, c_1, c_2,

$$\text{then} \qquad \frac{c_1}{c_2} = \frac{\sin d_1°}{\sin d_2°},$$

$$\text{or,} \qquad \sin d_1° : \sin d_2° : : c_1 : c_2.$$

Example.—Let the coil of the galvanometer be turned through $d_1^\circ = 18^\circ$ when a current, c_1, is flowing through the coil from one battery, and through $d_2^\circ = 37^\circ$ when a current, c_2, flows through it from another battery. Then the currents are not proportional to these angles, but to their respective sines (see last Table).

For $\sin d_1^\circ : \sin d_2^\circ :: c_1 : c_2$

$$\sin 18^\circ : \sin 37^\circ :: c_1 : c_2$$

$$\cdot 3 : \cdot 6 :: c_1 : c_2$$

$$c_2 = c_1 \frac{\cdot 6}{\cdot 3} = 2 c_1,$$

or the current in the second case is twice as strong as in the first.

Lecture XI.—Questions.

1. Sketch and describe an experiment whereby you can prove the directions of the magnetic field set up inside and outside of a circular current-carrying wire.

2. A short horizontal freely-suspended magnetic needle is placed midway between two long (vertical) straight parallel wires through which the same current is passing, up one and down the other. How does the needle behave? The same needle is now placed at the centre of a single turn of wire formed into a circle placed vertically, and if the same strength of current be passed through this wire as through the straight wires, how does the needle now behave? Compare the strengths of the magnetic fields midway between the parallel wires and at the centre of the wire circle due to the current in the two cases.

3. Sketch the direction of the magnetic lines of force surrounding a circular current-carrying wire joined to a battery when the current flows, 1st, from right to left; 2nd, when from left to right. Introduce a right hand, properly placed outside and inside the wire, with the outstretched thumb and fingers in the proper direction.

4. Sketch and describe a simple tangent galvanometer with a single coil of wire. Why is such an instrument called a tangent galvanometer?

5. Compare the relative strengths of the currents passing through the coil of a tangent galvanometer when the observed deflections of the needle are 27° and 45° respectively.

6. Why is it necessary to have a comparatively small needle and a coil of large diameter in a tangent galvanometer?

7. Sketch and describe a simple sine galvanometer. Why is such a galvanometer called a sine galvanometer? How is it used for comparing the strengths of currents?

8. Why can a long needle be used with a sine galvanometer and not with a tangent galvanometer?

9. Compare the relative strengths of the currents passing through the coil of a sine galvanometer when the angles through which the coil has been rotated before the needle again stands at zero are 30° and 45° respectively.

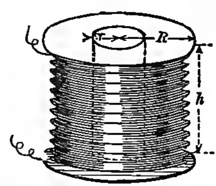
LECTURE XII.*

CONTENTS.—Electro-Magnetic Solenoid—Magnetic Field Inside a Solenoid and its Direction—Magnetic Field Outside a Solenoid and its Direction—Combined Effect of the Magnetic Fields Due to a Permanent Magnet and an Electro-Magnetic Solenoid—Sir William Thomson's Graded Tangent Galvanometers—Sir William Thomson's Mirror Galvanometer—Simple Astatic Galvanometer—Questions.

Electro-Magnetic Solenoid.—In the last Lecture we explained the general configuration and the direction of the lines of force of the magnetic field produced by a circular current of one or more turns where the width of the coil was small relatively to its diameter, and we gave two practical examples of its application in the form of tangent and sine galvanometers.

We shall now treat of the properties of Electro-Magnetic Solenoids and their practical application.

DEFINITION OF A SOLENOID.—*If an insulated wire is coiled upon a cylindrical bobbin* (just as cotton-thread is wound upon a pirn or reel, so that the several turns of wire are closely adjacent and of two or more layers deep), *such an arrangement is called a solenoid when the length of the coil is not small compared to its diameter.* The accompanying figure illustrates a solenoid, and the same becomes an Electro-Magnetic Solenoid when an electric current is passing through its coils of wire.†



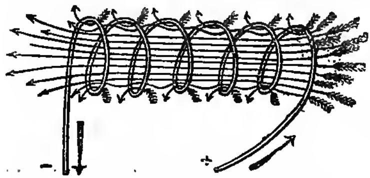
SOLENOID OR BOBBIN CONTAINING INSULATED WIRE.

Magnetic Field Inside a Solenoid and its Direction.—From what we stated in the last Lecture regarding the direction of the magnetic field due to

* If this Lecture should be found too long, or in some parts too advanced, then the teacher or student may omit the description of Sir William Thomson's graded and mirror galvanometers.

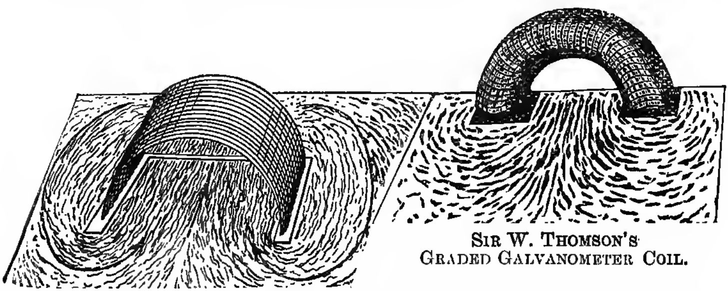
† See Rankine's "Useful Rules and Tables," 7th edition, p. 437, or Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables," 6th edition, p. 402, for how to calculate the length of any particular size of wire that can be coiled upon a circular bobbin. Also see Appendix to Part II.

a circular current, the student will at once understand by an inspection of the three following figures that when a current circulates through a long length of conductor coiled into the form of circles placed close alongside of each other, the direction of the magnetic field along and parallel to the axis of the solenoid (inside) is straight and tolerably uniform in strength to within a short distance of the ends of the solenoid. The field due to each current-turn of wire assists the neighbouring current-turn, so that, upon the whole, we have (as illustrated by the first figure *) a collection of magnetic lines of force arranged not unlike that of bowmen's arrows placed within their hide-bound sheath.



MAGNETIC FIELD WITHIN A HELIX OR SOLENOID.

EXPERIMENT X.—The student may easily prove the truth of the above statement (or the experiment may be shown to a class)



MAGNETIC FIELD INSIDE AND OUTSIDE A SOLENOID AND A GALVANOMETER COIL ALONG THE PLANES OF THEIR AXES AS DEPICTED BY IRON FILINGS.

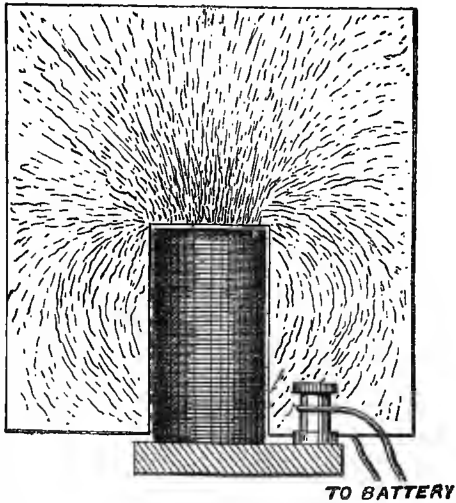
by placing a piece of cardboard covered with paraffined paper inside and surrounding the outside of the solenoid and scattering soft iron filings over the paper whilst the current flows through the wire.† The direction of the field is indicated by the arrows in each case.

The Magnetic Field Outside a Solenoid and its Direction.—The last two figures also illustrate the direction of the magnetic field outside the solenoids.

* We have purposely drawn only an open spiral or helix of wire in the above figure, and a single layer in the next figure, in order to be able to show more clearly the directions of the several magnetic lines of force.

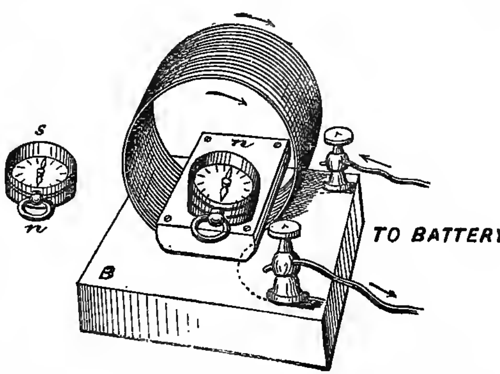
† See Part I., Lecture III., page 21, for how to fix the iron filings, and thus obtain a permanent record of the magnetic field.

EXPERIMENT XI.—In order to bring home to the mind of the student that the contour of the field outside an electro-magnetic solenoid is identical with that of a permanent cylindrical bar magnet of the same length and width, we would advise him to place a piece of cardboard covered with paraffined paper outside the solenoid *only*, and thereby produce by means of iron filings, in the manner already described, a permanent picture similar to the accompanying figure. To do so effectively the solenoid must be fixed with its axis horizontal, the plane of the card should pass through the horizontal axis of the solenoid.



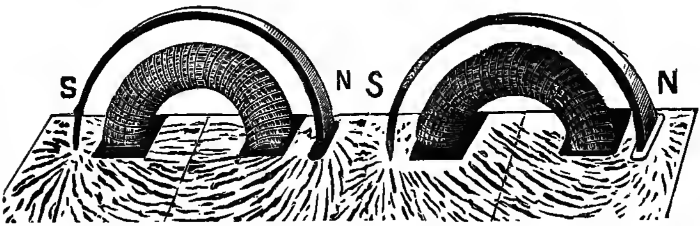
MAGNETIC FIELD OUTSIDE A SOLENOID AS DEPICTED BY IRON FILINGS.

EXPERIMENT XII.—Sufficient proof of these two last statements may be obtained by simply taking a small compass test-needle and placing it in various positions inside and outside the solenoid, having first observed that the planes of the coils are coincident with that of the magnetic meridian.



TESTING THE DIRECTION OF THE CURRENT'S FIELD INSIDE AND OUTSIDE A SOLENOID BY A COMPASS-NEEDLE.

Combined Effect of the Magnetic Fields Due to a Permanent Magnet and an Electro-Magnetic Solenoid.—EXPERIMENT XIII. —1. Place a semicircular permanent magnet over the short solenoid illustrated by the third figure in this Lecture, and see that the line joining the poles of the magnet lies fair in line with the magnetic meridian.



MAGNETIC FIELD DUE SOLELY TO CURVED MAGNET, AS DEPICTED BY AID OF IRON FILINGS.

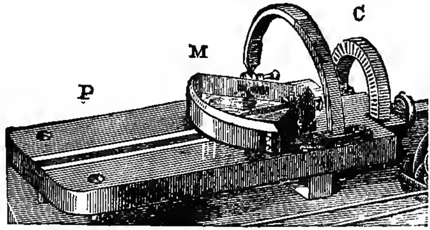
MAGNETIC FIELD DUE TO THE COMBINED EFFECTS OF CURVED MAGNET AND CURRENT THROUGH COIL, AS DEPICTED BY IRON FILINGS.

2. Place a piece of cardboard with paraffined paper inside and outside the coil as before.

3. Before passing a current through the coil, take an impression of the magnetic field by means of iron filings, and also note the direction of the lines of force by your small compass test-needle. The direction of the field is straight across between the poles of the magnet, as illustrated by the accompanying figure.

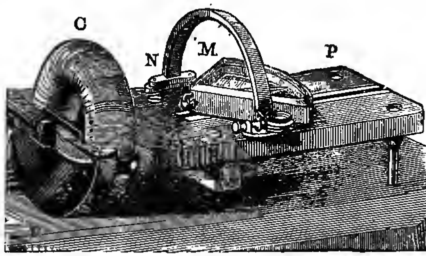
4. Having substituted a fresh piece of paraffined paper, turn on the current through the coil, and again take an impression. The contour of the field is now considerably changed, not only from what it was in the last figure, but also from what it was as seen by the third figure in this Lecture. In fact, the field is now a combination of these two fields, the one due to the permanent magnet and the other due to the current. The filings take up a slanting position from left to right. If you were to substitute a fresh card and to reverse the current through the coil, then the slant of the direction of the filings would be from right to left. A freely-suspended magnetic needle moved along the axis or centre line of the coil would take up a position coincident with that of the iron filings. The farther the needle is removed from the coil the less will the deflection be from the magnetic meridian or plane of the coil.

Sir William Thomson's Graded Tangent Galvanometers.—From the foregoing experiments and remarks the student will now have no difficulty in understanding the principle and action of these two practical instruments. The first figure illustrates the form used for measuring strong currents, and the second that for weak currents or potentials, *i.e.*, the electrical pressure or difference of potential between any two points in an electric lighting circuit, such as the pressure between the + and − poles of the battery or the dynamo, or the pressure between the terminals of an electric lamp.



GRADED TO AMPERES, FOR STRONG CURRENTS.

The only difference that may be mentioned here between the two instruments is this, that the first is fitted with a coil, C, consisting of a few turns, or of a single turn of thick copper strip, whereas in the second instrument the coil, C, consists of many turns (6000 to 10,000) of fine German-silver wire insulated with silk. In each instrument the coil may be regarded as a very short solenoid fixed to one end of a wooden platform, P. A V groove is formed in the centre line of this platform (*i.e.*, truly below the axis of the coil, C), so that the quadrant-shaped case, or little brass box marked M, for Magnetometer (containing the freely-poised magnet, with its attached index or light aluminium pointer, and scale underneath the same), may be moved to any desired distance from the centre of the coil, C. The semicircular permanent magnet marked N and S is suitably supported by outstanding projections from the magnetometer case, M, and consequently this magnet moves along with the needle and its case. From what we said under the previous heading, the student will see that the greatest deflection of the needle is obtained for any particular current strength when the magnetometer needle is exactly at the centre of the coil, C, and that the further the needle is moved therefrom the less will be the deflection, because the current-carrying coil's field gets weaker the farther away you get from the coils.



GRADED TO VOLTS, FOR WEAK CURRENTS OR POTENTIALS.

The V groove is so graded or graduated that for each position of the needle along the same, *the exact value of the deflection* obtained with either instrument is found by the simple arithmetical operation of dividing the deflection in degrees by the number marked immediately under the front of the magneto-*

* The first instrument has its V groove so graded that the result of the above rule produces practical units of current in amperes, and for the second instrument practical units of electro-motive force, or electrical pressure, or potential in volts.

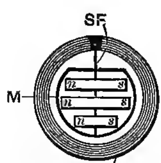
*meter case on the platform scale, and then multiplying this result by the intensity of the magnetic field on the needle.**

This graded scale consequently affords with these instruments a much wider range of observation than if the position of the magnetic needle had been fixed.

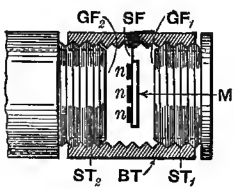
There are two points of importance which it is necessary to observe when aiming at accurate measurements with these instruments—

1. See that the instrument is so placed (when no current is passing and *no magnet* is near the magnetometer) that the aluminium index points to zero.
2. Make certain that you know the precise value of the strength of the semicircular magnet at the time, for bar magnets (as we saw by experiments in Part I.) lose their strength.

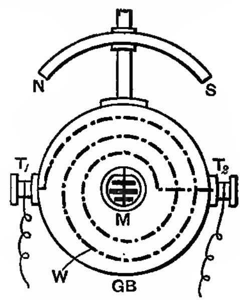
Sir William Thomson's Mirror Galvanometer.—This useful and well-known instrument is one of the most delicate and accurate appliances used by electricians for determining the Resistance to the flow or passage of currents through conductors and insulators, the Current Strength through a conductor, the Electrical Pressure or Potential supplied by a battery or other source of electrical energy, and the capacity of an insulated conductor or the charge given to it. It was also applied by its inventor to the production at the receiving end of Telegraphic Signals sent in at the sending end of long submarine cables, such as those crossing the Atlantic Ocean. It is still used for



Cross Section of Brass Tube, showing Back of Mirror.



Longitudinal Section of Brass Tube, showing Mirror in Dead-Beat Chamber.

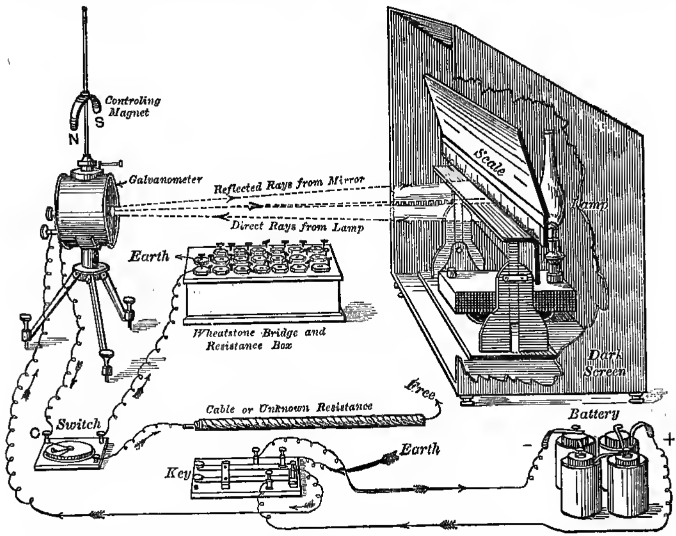


Back View of Mirror Galvanometer, showing Winding, &c.

that purpose whenever there takes place a break-down or failure of his Siphon Recorder, the only other instrument yet devised which is capable of such delicate and accurate work. As will be observed from the two accompanying sets of figures, it consists of a solenoid or hollow brass bobbin filled with copper wire covered with a double layer of silk thread. One end of this wire is soldered to one outstanding terminal, T_1, whilst the other end is soldered to the other terminal, T_2. Under certain circumstances, such as for testing and telegraphic signalling purposes, the galvanometer may have two or more separate coils of

* *I.e.*, the number marked by the maker on the semicircular magnet, plus the Earth's field, which is generally taken as $= \cdot 17$ in the British Islands. See Rankine's "Useful Rules and Tables," 7th edit., pp. 396, 397.

wire of different lengths and number of turns wound upon the same bobbin, the ends of each coil being suitably attached to their respective terminals, fixed outside the galvanometer bobbin; in fact, the coils of this instrument are wound to suit the particular class of work for which it is intended. For strong currents or the measurement of low resistances, thick wire with a few turns is employed, whereas for weak currents or the measurement of great resistances many thousand turns of fine wire are necessary. Inside the central hole of the bobbin is placed a brass tube, BT, containing a very light, truly ground, curved, microscopic glass silvered mirror, M, suspended from a small hole in the upper side of this tube by means of a very fine cocoon silk fibre, SF, attached to BT by shellac. Upon the back of the mirror are fixed (by shellac varnish, previous to suspending the mirror inside the tube) three or four tiny magnets with their axes parallel, and their N-poles pointing in one



SIR WILLIAM THOMSON'S MIRROR GALVANOMETER AND CONNECTIONS, &c., JOINED UP FOR TESTING INSULATION RESISTANCE.

direction. The three or four little magnets thus form a compound magnet of greater strength than a single one of the same or even greater weight. These thin magnets, when the galvanometer is in use, hang horizontally, and they are about $\frac{1}{64}$ inch or less in thickness, and from $\frac{1}{4}$ to $\frac{3}{4}$ inch in length for mirrors varying from $\frac{3}{8}$ to 1 inch in diameter, the smaller sizes of mirror, which, together with the magnets, do not weigh more than 2 grains, being used for the most delicate testing galvanometers, while the larger sizes are used for class demonstration instruments. To render the mirror "dead-beat" in its action, *i.e.*, so that it may come to rest almost instantly, without swinging to and fro for a number of times when deflected by a constant current, or when the current ceases, the mirror and compound magnet are not only made as light as possible, but they are encased between two plain glass faces, GF_1, GF_2, fitted to the ends of two screwed tubes, ST_1, ST_2. These tubes may be screwed towards or from the mirror, M, until any desired range of movement and "dead-beat"

action is given to the latter. When the mirror is deflected from rest, it forces the pent-up air within the central chamber of the brass tube, BT, against each of these plain glass faces, GF_1 and GF_2, and the air reacting therefrom as a "couple" force upon the mirror, causes the mirror to take up a position of rest more or less quickly according as the glass faces are near or far from the same. This gives each movement of the mirror greater definiteness without detracting from its sensitiveness, and thus saves an immense amount of time and annoyance to the electrician ; for there is nothing more tantalising than to work with an instrument whose magnet keeps on swinging to and fro for a number of times before a definite reading of its position can be ascertained.

As will be readily understood from the perspective figure, the deflections of the mirror are rendered visible by aid of a paraffin-oil lamp and a scale. The combined lamp and scale are placed (if necessary) within a dark screen, and at about three feet distant from the mirror. The direct rays from the lamp to the mirror pass through a vertical slit in the wooden frame (supporting the lamp and scale), and are reflected back upon the scale by the mirror. A thin vertical wire is often fixed in this slit, with a lens in front of the same, so that when the proper focus of the lens and scale has been found, a definite vertical black line (of the image of this fine wire) is reflected by the mirror upon the scale, whereby the precise deflection of the "spot" to the right or to the left of the centre or zero division of the scale can be read off with ease and accuracy.

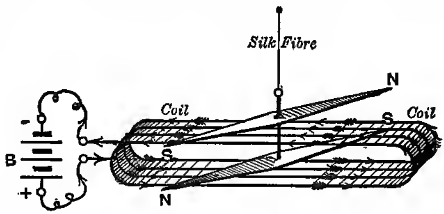
Above the galvanometer coil is fixed a controlling magnet, NS, which may be turned round horizontally (with or without the aid of the tangent screw on the top of the galvanometer), so as to act by magnetic induction upon the compound magnet on back of the mirror, and thereby turn the latter, and therefore the mirror, to any desired position. For example, it may be used to bring the "spot" of light to zero on the scale, or to any division to the right or left of zero. This magnet, NS, may also be elevated or depressed along its vertical central guide-rod, so as to cause its magnetic field to act with more or less restraining force upon the mirror's magnet, and thus render the latter more or less directly sensitive to the current's field. The most sensitive position for the whole system is when the coil of the galvanometer is placed in the magnetic meridian, and when the controlling magnet, NS, is elevated so that its force upon the mirror's magnet just balances the action of Earth's field upon the same,* *i.e.*, when the mirror's magnet is rendered astatic, and therefore free to be acted upon *solely* by the current's field. Since the angle of deflection of the spot of light upon the scale is double the deflection of the mirror (owing to the incident and reflected rays of light), it has been found that the deflections of the spot on the scale are practically proportional to the strengths of the currents passing through the galvanometer coil within the limits of the range of the scale as supplied with these instruments. This is an immense advantage in favour of this instrument, as it saves much calculation.

We shall not attempt here to explain the precise arrangement of the rest of the testing apparatus illustrated by the last figure further than to observe that the battery, key, switch, galvanometer, combined Wheatstone-bridge resistance box, and the cable which is the unknown resistance to be found by aid of these appliances, are joined up, by means of the various wires shown, for the purpose of measuring the Insulation Resistance by the Leakage Current which takes place through the dielectric or insulating material of a submarine or an underground cable, or over the insulators of an aerial line employed for electric lighting or transmission of power. We must defer this pleasure, owing to the necessarily more complex nature of the problem, to our Advanced

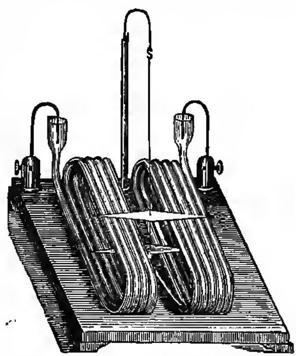
* The student should here refer back to Experiment XXIV., Part I., Lecture VIII., and note the second figure on page 67, wherein the Earth's magnetism and a bar magnet balance each other with respect to the magnetic needle.

Treatise on Magnetism and Electricity. At present, students who may desire to know more about the matter than has just been given, are referred to page 146 of our Electrical Pocket-Book, where they will find a complete explanation with an example.

Simple Astatic Galvanometer.—We have just described in connection with the mirror galvanometer how the directive action of the Earth's magnetism upon a suspended magnet or needle may be lessened, or even exactly counteracted, by the employment of a compensating or controlling magnet properly placed at a certain distance vertically above (or below) the needle. There is, however, another method for effecting the same object, and one which is more frequently adopted in practice, viz., by using an "astatic pair" of magnetic needles like that described and illustrated at page 68 of Lecture VIII. (Part I.), in combination with one or two coils of current-carrying wire. This combination is termed an Astatic Galvanometer.

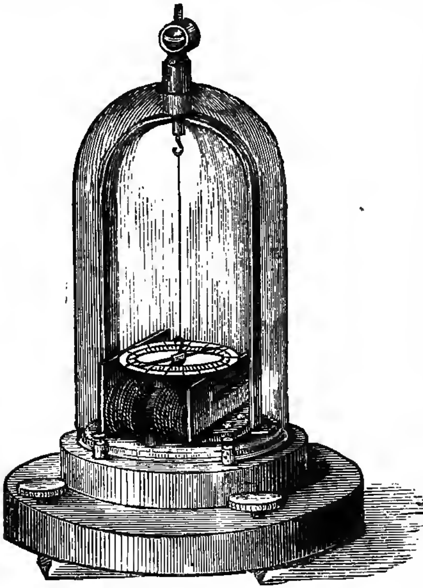


THEORETICAL FIGURE OF A SIMPLE ASTATIC GALVANOMETER.


LECTURE-ROOM FORM OF A SIMPLE ASTATIC GALVANOMETER.

The following three figures serve to illustrate this galvanometer in its simplest form. The first figure is a theoretical sketch of the coil, astatic pair with silk fibre suspension and battery. It shows the direction of the current from the + pole of the same through the several turns of the coils and back to the − pole of the battery. The second figure indicates the style in which it is made for lecture-table demonstrations; and the third figure the practical instrument as it is used in the laboratory or testing-room. The galvanometer consists of one coil of insulated wire wound upon a hollow ▭-shaped bobbin. The lower needle can move freely within the hollow space of the coil, whilst the upper needle moves parallel to and near the uppermost layer of wire. Attached to the upper end of the connecting wire binding the two needles rigidly together is fixed a light glass or aluminium pointer parallel to the magnetic axis of the needles

Between this pointer and the upper needle is fixed a horizontal circular card graduated in degrees. The base of the instrument is supported by three levelling screws, and the delicate parts are covered by a bell-shaped glass jar, which protects them from dust and damp, and the needle from air draughts. The upper end of the silk fibre suspension is attached to a small hook terminating in an adjusting and elevating screw and nut, whereby the pointer may be brought to zero, and the needles raised or lowered at pleasure. When not in use, the fibre suspension is lowered until the pointer rests upon the card, and thus all stress (due to the weight of the needles, &c.) is removed from the fibre, which should be very fine, so as to make the torsional error a minimum. It will be readily seen from an inspection of the first figure how each portion of the current flowing in the coil acts with the same directive sense upon the lower needle, and also how the portions of the current in the upper layers of the coil act similarly upon the lower and upper needles. The instrument is consequently not only more sensitive (and therefore better adapted for the measuring of weak currents than the single-needle one of the same general shape), owing to the principle of the astatic pair diminishing the effect of the Earth's field upon the needles, but also owing to this *extra* action upon the upper needle of one side of the current-carrying coil.



PRACTICAL TESTING-ROOM FORM OF SIMPLE ASTATIO GALVANOMETER.

In the finer, more accurate, and expensive forms of astatic testing galvanometers, there are two circular coils or solenoids, just like those employed in mirror galvanometers, with fine compound magnets at the centre of each, to the upper set of which is attached a mirror; but we must leave the detailed description of this more complicated form to our Advanced Text-Book.

LECTURE XII.—QUESTIONS.

1. What is a solenoid? When does a solenoid become an electro-magnetic solenoid? Sketch a solenoid joined up to a battery, and show by signs and arrows not only the polarity of the battery, but also the direction of the current through the wire.

2. Give a sketch showing the condition and direction of the magnetic field *inside* and *outside* an electro-magnetic solenoid, as indicated by the aid of soft iron filings and a compass-needle.

3. Give a sketch showing the combined effects of the magnetic field due to an electro-magnetic field and a superimposed permanent semicircular bar magnet.

4. Sketch and describe Sir William Thomson's graded tangent galvanometers for measuring strong currents and electrical pressures. Having obtained a deflection with one or other of these instruments, how do you find its current or the electrical pressure value in practical units?

5. Sketch in section and describe fully the construction and action of every part of Sir William Thomson's mirror galvanometer. How are the deflections of the mirror observed? Are the deflections as observed proportional to the current strength passing through the galvanometer coil, and if so, why?

6. Describe the construction, action, and use of a common or simple astatic galvanometer.

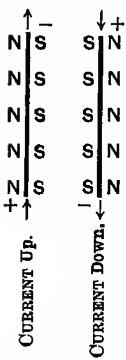
7. How is it that a galvanometer with astatic needles is more sensitive than the same instrument would be if furnished with only a single needle? (S. and A. Exam., 1886.)

8. Why is an astatic galvanometer better adapted for the measurement of weak currents than a galvanometer with a single needle? (S. and A. Exam., 1889.)

LECTURE XIII.

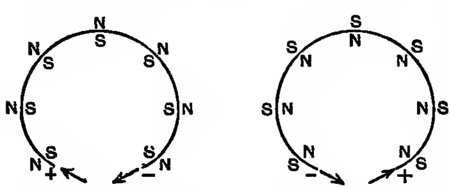
CONTENTS.—Magnetic Polarity Due to a Straight Current—Magnetic Polarity Due to a Circular Current—Magnetic Polarity of an Electro-Magnetic Solenoid—Given the Direction of the Current in a Solenoid, to Find the N and S Poles of the Solenoid, and *vice versa*—Specimen Question and Answer—Questions.

Magnetic Polarity Due to a Straight Current.—In Lecture IX., Experiment III., we discussed the direction of the magnetic field due to a straight current. We there found by experiment the direction which a freely-suspended magnetic needle takes up in virtue of the action of the current's field upon the needle's field.



EXPERIMENT XIV.—Looking at the two accompanying figures, and bearing in mind what we have frequently proved by experiment, let a compass-needle be moved up or down close to and along the *farther side* (*i.e.*, the side away from the reader) of the current-carrying wires, which are supposed to lie in the plane of the paper. Then the **N** and **S** poles of the needle take up the positions indicated by the **N** and **S** letters. Consequently we may regard an electric current as if it were producing **North** and **South** polarity of that direction along that side of the whole circuit of the current-carrying wire.*

Magnetic Polarity Due to a Circular Current.—EXPERIMENT XV.—Now bend the wire in the last experiment into the circular form, and pass a freely-suspended dipping-needle along the farther side of the current-carrying wires, which are supposed, as before, to lie in the plane of the paper. We observe that the **N** and **S** poles of the needle take up the positions indicated by the **N** and **S** letters. Consequently



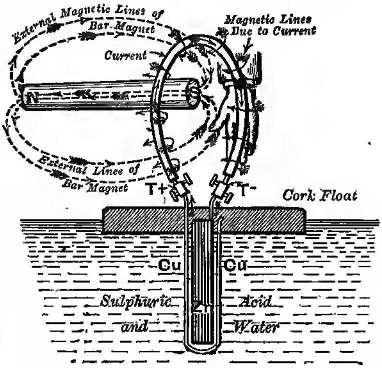
* Although this is an arbitrary expedient for facilitating the explanation in regard to the above and similar cases, the student must not lose sight of the *true closed* curved nature of the current's field, already frequently referred to.

we may regard the current in the circular wire as producing **North** and **South** polarity along each circuit, as shown by the two figures.

EXPERIMENT XVI.—To prove this important fact in another way:—

(1.) Take a stiff copper wire and bend it into a circle.

(2.) Connect the free ends of this wire to the terminals, T+ and T−, of a floating battery cell, *i.e.*, connect one end of the wire to one end of a strip of sheet-copper about 1 inch broad, bent into the form of a U (marked *Cu* on the annexed figure, for *Cuprum*, the Latin for copper), and the other end of the wire to a piece of zinc of the same breadth (marked *Zn* for zinc); both plates being suspended in a bath of dilute sulphuric acid from a cork or wooden float.



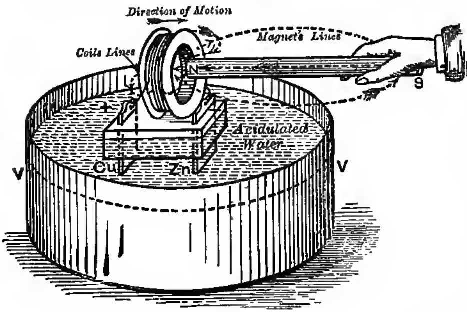
POLARITY OF A CIRCULAR CURRENT, SHOWING ATTRACTION BETWEEN THE SAME AND A BAR MAGNET.

(3.) Now hold, say, the **S**-pole of a bar magnet towards the centre of the **North** side of the current-carrying wire. Immediately the wire will be attracted towards the magnet (carrying the float and cell along with it), and then it will move along the magnet until it reaches the middle or equator of the same. Present the **N**-pole of the magnet to this **North** side of the wire, and immediately repulsion takes place between the two. The wire will move away for a short distance, and then turn bodily round with the float and cell, until the **South** side of the wire presents itself to the **N**-pole of the magnet, when the effect of attraction will take place just as in the previous case, until the wire moves along the magnet to the middle of the same.

In the figure we have shown by arrows, not only the direction of the current along the wire, but also the direction of the current's circular field around the same, and the bar magnet's field, with a right hand so placed on the wire that the outstanding thumb indicates the **N**-side or polarity of the current's magnetic lines of force. From these indications you cannot fail to observe that the direction of the current's field is in the same direction as the magnet's lines of force *through itself*. These two forces therefore act in sympathy, as it were, with each other; and since the

magnet is fixed, the current-carrying wire, which is free to move, must be urged towards and along the line of the magnet's axis until it reaches the equator of the same, or the position of equilibrium between the two forces in action.

Magnetic Polarity of an Electro-Magnetic Solenoid.—Experiment XVII.—Adopting precisely the same floating device and battery cell as in the last experiment, but substituting a short solenoid or coil of insulated wire for the single turn, you observe the same effects, viz., when the **N**-pole of the bar magnet is presented towards the centre of the **S**-side of the solenoid, the latter is attracted, whereas when the **N**-pole is presented to the **N**-side of the coil, repulsion takes place. Or, generally speaking, we prove that a solenoid through which a current is passing possesses polarity in the same way as if it were a magnet, and *that unlike poles attract each other and like poles repel each other.*



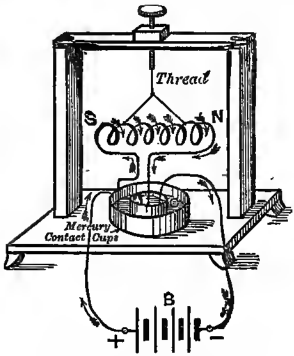
Polarity of a Solenoid, showing Attraction between it and a Bar Magnet.

Experiment XVIII.—1. You may vary the demonstration by substituting for the short coil in the last experiment a long spiral or helix of wire, either suspended from a thread (as shown by the first of the two following figures), or supported by a floating battery cell (as shown by the second figure). These spirals are equivalent in their magnetic action to as many circular currents as there are number of turns of wire, since their axes lie in the same straight line. If you present the **N**-pole of a bar magnet to a certain end of each spiral, you observe that it is repelled. You accordingly conclude that this end must be the **N**-end of the spiral. If you present the same pole of the bar magnet to the other end of the spiral, you get attraction, whereas if you hold the **S**-pole of the bar magnet towards it, you find the spiral repelled, and you again conclude that this must be the **S**-end of the spiral.

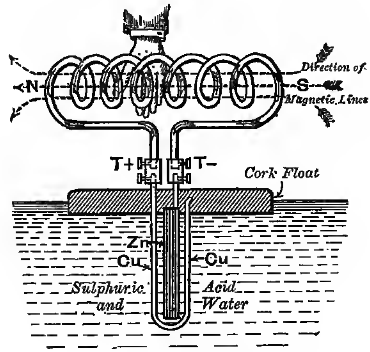
2. Suppose you remove all magnets and iron from the vicinity of these solenoids or spirals, and still permit the current to flow through them, you will find that they very soon take up a position with their axes in the plane of the earth's magnetic meridian,

just like that of a compass-needle or suspended bar magnet, owing to the mutual action between their current's field and the Earth's magnetic field.

3. If you place in the same glass bath or porcelain basin, containing sulphuric acid and water, a long floating spiral of small diameter (like that in the second figure), and a short open coil (like



SUSPENDED WIRE SPIRAL OR SOLENOID.



FLOATING WIRE SPIRAL OR SOLENOID.

INDEX TO PARTS.

N,S,	represents	North and South poles of the solenoids.
I,O,	„	Inner and Outer cups containing mercury.
B	„	Battery.
Cu	„	Copper plate of battery cell.
Zn	„	Zinc „ „ „
T+,T−	„	Terminals (positive and negative) of cell.

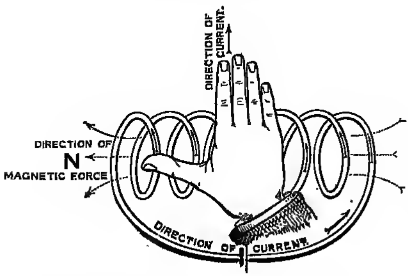
that on the previous page), these two current-carrying coils will act towards each other, in the first instance, like two floating magnets, for you will find that they turn round so as to present their unlike poles to and then attract each other.

Finally, the long spiral will penetrate the open coil as far as the cork floats will permit. Electro-magnetic spirals or solenoids, therefore, possess magnetic polarity, and act like magnets.

Given the Direction of the Current in a Solenoid, to Find the North and South Poles of the Solenoid, or vice versâ.*

* The two following rules, devised by the author, seem to be much more easily applied and remembered by students than the rules generally given in text-books, wherein the experimenter has to suppose himself swimming in the wire with the current, or looking normally at one end of the solenoid, and then think whether the current is moving in the same or in the opposite direction to the moving hands of a clock or watch. See Appendix, Part II.

Rule 1.—If you know the Direction of the Current in the winding, then by placing your **right hand**, as shown, the *thumb points in the direction of the N-pole of the solenoid or spiral.*

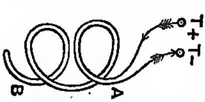


Rule 2.—Ascertain the **N**-pole of the spiral or solenoid by means of a compass-needle, then by placing your **right hand** on the solenoid (as shown by the figure) so that the outstretched thumb points in the direction of the **N**-pole (or where the magnetic lines of force leave the coils), *the fingers will point in the direction of the current passing through the windings.*

Specimen Question and Answer.

Question.—A guttapercha-covered copper wire is wound round a wooden cylinder, AB, from A to B. How would you wind it back from B to A (1) so as to increase, (2) so as to diminish, the magnetic effects which it produces when a current is passed through it? Illustrate your answer by a diagram drawn on the assumption that you are looking at one end. (S. and A. Exam., 1889.)

Answer.—(1.) Continue winding the wire from B back to A in the *same* way as you would wind thread upon a pirn, *i.e.*, keep turning the cylinder in the *same* direction as when winding on the wire from A to B. (2.) Before commencing to wind *back* the wire from B to A, bind the last turn to the wooden cylinder, and then revolve the cylinder in the *reverse* direction to the way in which it was turned when winding on the wire from A to B.



N.B.—The two figures illustrated on page 119 show left-handed and right-handed spirals. Since the current is thus sent through the windings in the different directions shown, although starting from the same end, it produces opposite polarity in the two coils. Consequently, in Case (2), if we put on the *same* number of turns of wire from B to A, but in the *reverse* direction to that from A to B, there would be no electro-magnetic effect whatever, for the magnetic field due to the one layer of current-carrying spiral would cancel that of the other, seeing that the current doubles back on itself, as shown by the above small figure.

Lecture XIII.—Questions.

1. What do you understand by the expression, "Magnetic polarity of a straight current"?

2. A current flows through a circular wire laid on the table, in the direction of the motion of the hands of a watch. Give a sketch illustrating the polarity of the faces of the wire circle.

3. You present the N-pole of a bar magnet towards the centre of a floating copper ring through which an electric current is flowing in the direction of the hands of a watch as viewed from the side to which the bar is presented. Sketch and explain what will happen. Show the current's and the magnet's fields, and place a right hand on the wire to show the direction of the current's field. What will happen if you present the S-pole instead of the N-pole of the bar magnet to the same side of the wire?

4. Sketch and describe by an index the floating solenoid and battery. Show how it behaves when the pole of a magnet is presented to it. What occurs when another floating solenoid with battery is placed beside it?

5. Are solenoids similar to magnets, and if so, in what respects? Give sketches showing how you would find out which was the N-pole of a solenoid, (1) by aid of a compass-needle, (2) by aid of a bar magnet, (3) by aid of nothing else than your right hand, if you know which way the current flows through the coils.

6. A piece of copper wire is wrapped spirally round a ruler from end to end, and the ruler is hung horizontally, so that it can turn about its centre while a current is passing through the wire. How can you tell in which direction the current is passing, (1) by using a bar magnet? (2) without using anything but your right hand?

LECTURE XIV.

CONTENTS.—Magnetisation of Iron and Steel by an Electric Current—Definition of an Electro-Magnet—Magnetic Field of an Electro-Magnet—Attractive Force of an Electro-Magnetic Solenoid towards an Iron Core—Blyth's Current Meter—Horseshoe Electro-Magnets, with Practical Examples—Alteration in the Length of Iron when Magnetised—Questions.

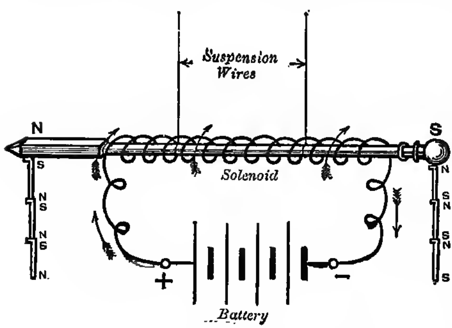
Magnetisation of Iron and Steel by an Electric Current.—In the year 1820, very soon after Oersted published his discovery of the magnetic influence of an electric current upon a magnetic needle, Sir Humphry Davy found out that pieces of iron and steel could be strongly magnetised by passing a current of electricity over them, or still better, round them, several times.

EXPERIMENT XIX.—1. Take a soft iron bar (a common poker will do very well).

2. Coil an insulated copper wire round the bar in the form of a spiral, as shown by the two following figures.

3. Suspend the bar by two copper wires or by twine.

4. Attach the ends of the insulated copper wire to a battery as shown, and thus pass a strong electric current through the spiral windings.

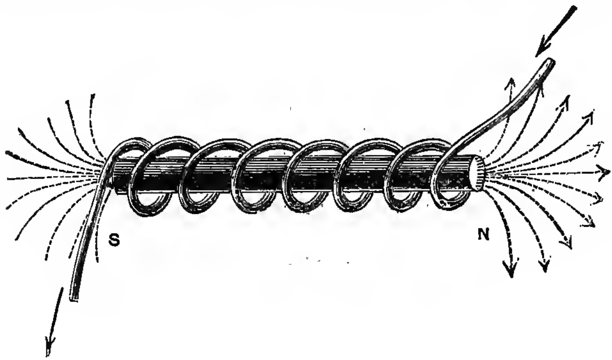


MAGNETISING A POKER BY A CURRENT.

5. Bring soft iron nails near to the ends of the bar. They become strongly magnetised by electro-magnetic induction, and great clusters of these nails may be hung from each end of the bar, if the current is strong.

6. Bring a compass-needle near to each end of the bar in turn, and you at once observe strong repulsion between one end of the bar and the needle's N-pole. This end of the bar is therefore a N-pole. Between the other end of the bar and the N-pole of the needle you observe equally strong attraction.

7. Holding the compass-needle in your left hand close to the **N**-pole of the bar, place your **right hand** on the wire spiral as

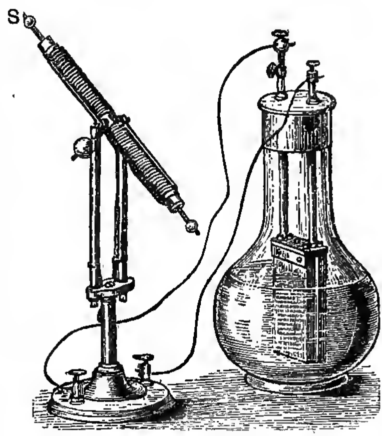


Magnetising a Bar of Iron or Steel by a Current.

instructed by *Rule* 2 (given on the previous page 120), and you thereby ascertain which way the current is flowing through the current-carrying wire.

8. Remove the bar from the spiral (see second figure) and again apply this same test. You at once find out that the **N** and **S** poles of the spiral are situated at the same ends as the corresponding poles of the bar when placed within the same; or, in other words, the spiral and the iron bar which it surrounds are similarly magnetised by the current.

You cannot help, however, observing that the strength of the bar's poles is many times greater than that of the spiral's poles without the bar.*



Balanced Electro-Magnet and Bichrome Battery Cell.

9. If you suspend the spiral with its bar (as in the first figure of

* At this stage we cannot expect the student to enter into and understand the formulæ which enable the electrician to calculate the exact strength of the magnetic field produced by a current passing through a solenoid, or the strength of the magnetism induced thereby in a piece of iron or steel inserted

Experiment XVIII.), you find that they turn round, and come to rest with their common magnetic axis in the plane of the earth's magnetic meridian. Or you may balance an electro-magnet, as shown by the last figure on page 123, and pass a current from the battery cell through the solenoid surrounding its soft iron core. The electro-magnet will act like a dipping-needle if its magnetic axis be placed in the plane of the magnetic meridian.

10. Take a strong bar magnet and hold it towards one pole of the poker, or towards one pole of the electro-magnet in the last two cases, and you get either strong repulsion or strong attraction between them, according as the poles presented towards each other are like or unlike.

11. If you substituted a hardened steel bar for the iron one within the spiral, you would find it converted into a strong permanent magnet. This was one of the best methods mentioned in Lecture I. for magnetising hardened steel bars.

A current of electricity therefore possesses the property of converting a bar of iron into a magnet, and the combination forms what is technically termed an **Electro-Magnet**; therefore—

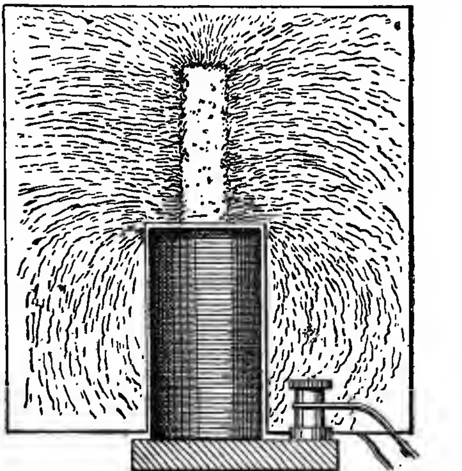
By Definition.—*If a bar of soft iron be introduced into a solenoid traversed by an electric current, that bar becomes strongly magnetic, and is called an* **Electro-magnet**.

If you refer back to Part I., Lecture IV., where we discussed the Molecular Theory of Magnetism, you will find that we considered each molecule to be a natural and complete little magnet by itself. You are, however, only capable of detecting their combined magnetic properties when they are so arranged that their magnetic circuits are not short-circuited amongst themselves, and consequently produce an external field. From this point of view, then, there is nothing extraordinary in the results which you have just observed. For, a current's magnetic force naturally acts upon the several molecules of the iron bar by magnetic induction (so as to induce them to take up the stressed condition with respect to each other favourable to the exhibition of an external field), very much in the same way that a permanent magnet acts on them. *In other words, the current's field simply renders evident the innate magnetism in the molecules of an iron or steel bar.*

Magnetic Field of an Electro-Magnet.—Referring back to Lecture XII., Experiment XI., you observe that the contour of the magnetic field of a solenoid as depicted by aid of iron filings

within the solenoid. For these formulæ see Rankin's "Rules and Tables," 7th edition, pages 308 and 309; also Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables," pages 379 to 380b, and pages 433 to 436.

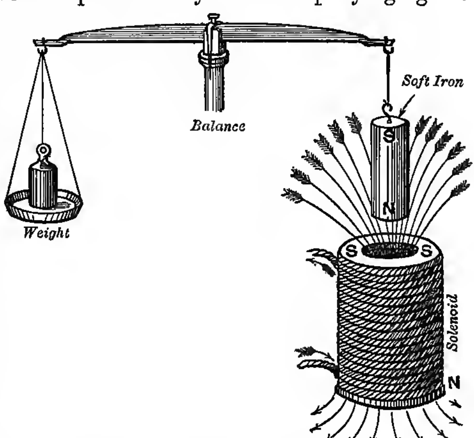
is very similar to that of a bar magnet's field. If you introduce a soft iron bar into the solenoid when the current flows through its coils, the combined fields would be of the same polarity but very much stronger than in the former case. The filings would thereby be attracted more closely together. In other words, the field would become more intense and defined. If you pulled out the iron bar (or core, as it is technically termed) to a certain distance from the solenoid bobbin, the field would take the form represented by the accompanying figure.



COMBINED MAGNETIC FIELDS OF A SOLENOID AND PROJECTING IRON CORE.

The bar would still retain its polarity, but the strength of its poles would be considerably diminished.

Attractive Force of an Electro-Magnetic Solenoid for an Iron Core.—The pull which an iron bar would experience under the attractive influence of the current's field may be tested by the following interesting experiment.



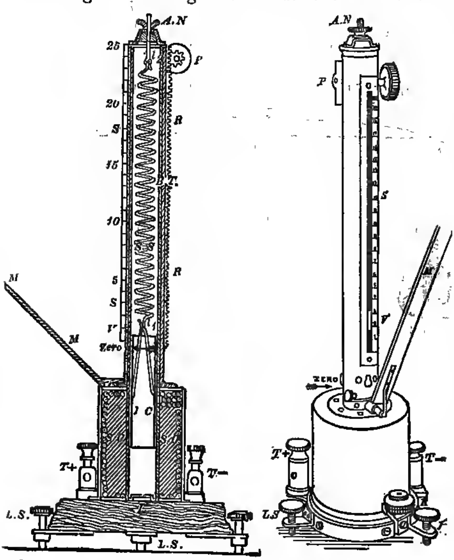
WEIGHING THE INDUCTIVE FORCE BETWEEN AN ELECTRO-MAGNETIC SOLENOID AND A SOFT IRON BAR.

EXPERIMENT XX.—Place a solenoid, with a current flowing through it, directly underneath a

cylindrical bar of soft iron attached to one arm of an ordinary balance, and put weights into the scale-pan on the opposite side of the beam until they balance the attractive force of the current's field upon the iron. If you test the ends of the iron bar, when in this position, by means of a compass-needle brought near to them, you will find that the bar is strongly polarised, and that the end next to the solenoid is of opposite sign to the near end of the latter, as shown by the diagram. You may vary the experiment by placing the solenoid nearer to or farther from the iron bar; also by lowering the bar more or less into the solenoid, and noting the different weights which are required to produce a balance for each position. The strongest pull will take place when the bar is nearly midway between the ends of the solenoid, for then the greatest number of the current's lines of force are concentrated within and by the bar of iron.

The solenoids and their iron cores for the regulation of Arc Lamps are frequently devised so as to act upon the above principle, or what has been termed "the sucking-coil method."

Professor Blyth's Solenoid Current Meter.—A practical instrument for measuring the strength of electric currents has been devised by Professor Blyth upon the above principle. Instead of using a balance and weights, which take a considerable time to adjust, he simply employs the natural and uniform resistance of a spiral spring to counterbalance the pull exerted by the current's field upon a thin hollow iron core. His reasons for using a thin hollow cylinder instead of a solid one are, that there shall be a minimum of residual magnetism left in the iron core after each test, and that the core may be practically magnetised up to saturation point by even a very weak current. Hence the pull exerted by the current's field upon the thin iron core is rendered proportional to the strength of the current passing through the solenoid, and is therefore directly indicated by the extension given to the resisting spiral spring.



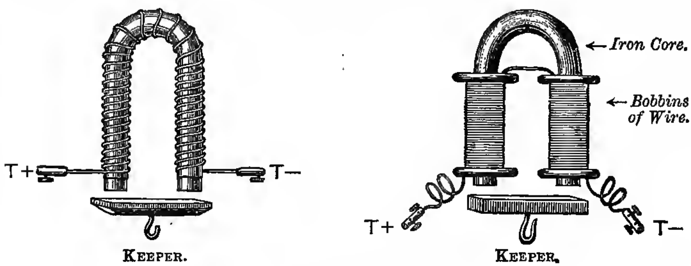
PROFESSOR BLYTH'S SOLENOID CURRENT METER.

In the figures, T + and T − are the + and − terminals which connect the

instrument in circuit with a battery or dynamo. The current passes from T + to T − through SC, the solenoid coil, which sucks the iron core, IC, into it against the resistance of the spiral spring, SS, attached by the loop l_1 to IC, and by the loop l_2 to AN, a screw for adjusting the zero marked on the IC by the arrow. A rack, R, and pinion, P, are fixed to the brass tube, BT, which slides freely inside the outer brass tube. A vernier, V, is fixed to BT, and indicates on the divided scale, S, fixed to the outer tube, the current strength or amperes flowing through SC. A mirror, M, shows simultaneously the zero on IC, and the position of the vernier on the divided scale S. L is a spirit level, and LS three levelling screws.

To Take a Test.—(1.) Level the galvanometer. (2.) Free the core, IC, by releasing three set screws not shown. (3.) Adjust by AN, R, and P, until the zero mark on IC agrees with zero pointer on outer brass tube, and at the same time the zero of the vernier, V, agrees with the zero of the scale. (4.) Then connect the instrument in circuit with the source of electric energy, and raise IC by R and P, until the zero on IC is again opposite the zero pointer on the brass tube. The reading of the vernier on the scale, S, gives, by reference to a constant (or a table carefully determined and drawn up by experiments in the laboratory), the current in amperes.

Horse-Shoe Electro-Magnets, with Practical Examples.—From what we have already stated regarding straight electro-



SIMPLE HORSE-SHOE ELECTRO-MAGNETS.

magnets, the student will now have no difficulty in understanding the construction and action of the horse-shoe form.*

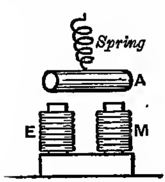
As will be seen from the above figures, the simple forms of horse-shoe electro-magnets consist of a bar of soft wrought-iron bent into the ∩ form, and then carefully annealed, in order that the magnetic resistance and the retentivity for magnetism may be as small as possible. The bar is either wound from end to end with one or more layers of insulated copper wire (as shown by the first figure) of the required size to carry the current to be passed through it without being unduly heated, or two solenoid bobbins of brass or wood are filled with the insulated wire, and

* See page 6, Part I., Lecture I., and the Appendix to Part I., for figures of the workshop or laboratory pattern of horse-shoe electro-magnet, and how to use it for the purpose of magnetising steel bars and needles. See Appendix to Part II., How to Make an Electro-Magnet.

firmly fitted on to the ends of the iron core (as shown by the second figure). Brass terminals or binding screws are then fixed to the ends of the wire, for the purpose of connecting these to the leading wires coming from a battery or dynamo.

The current, as it flows through the coils of insulated wire, evokes magnetism by induction in the iron core, and this induced magnetism reacts on the current's field by concentrating the magnetic lines of force within the core, so that we have a very strong field produced between the poles of the electro-magnet—a field which is equal to the sum of the current's field and the induced field in the core. If you desire to test the lifting force of the electro-magnet, you have only to place a soft iron keeper (of a cross section *at least* equal to the cross section of the core) below the magnet's poles, and fit the same with a hook from which you may hang weights. You thereby ascertain the force required to disengage the keeper from the poles of the core, due to different current strengths, as measured by Thomson's or Blyth's current meters previously described.

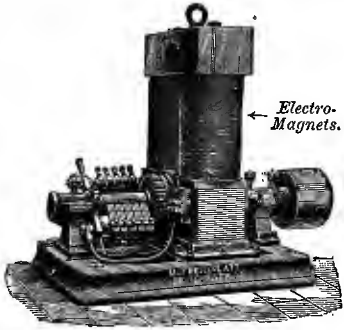
Horse-shoe electro-magnets are used for a great variety of useful purposes, besides that of magnetising bars of steel, and they are made in a variety of shapes, according to the work to be done by them. When it is desired that the electro-magnet shall respond quickly to a current of short duration, and demagnetise quickly whenever the current has ceased to flow, as in the case of the Morse telegraph instrument, then the bobbin windings and the cores are made as short as possible. When a long, steady continuous pull is required from an electro-magnet, as in the case of one form of apparatus for moving railway signals, then long solenoids and cores are advantageous. In the case of Sir William Thomson's siphon recorder for reproducing upon a moving ribbon of paper the telegraphic signals sent through long submarine cables, the magnetic field concentrated upon the moving coil requires to be constant and very intense; hence long electro-magnets are used. Edison, when he first devised his well-known dynamo machine for generating electricity for electric lighting purposes, adopted very long electro-magnets, but this was proved by Dr. John Hopkinson to be a mistake, since the magnetic resistance of the magnetic circuit was thereby unduly increased. By shortening the cores of the electro-magnet to less than one-half their former length, and increasing their sectional area as well as the number of layers of the solenoid wire, he raised the efficiency of the Edison dynamo



ELECTRO MAGNET FOR THE MORSE TELEGRAPH INSTRUMENT.

by fully 25 per cent. All good dynamos are now made with short, stumpy electro-magnets.

The ordinary house electric trembling bell is another practical instance of the advantages derived from the use of short electro-magnets. Here the current from the battery through the push and the coils of the electro-magnet solenoids is broken whenever the armature is attracted close to the poles of the cores, by the contacts between the back of the armature and the flat curved spring becoming separated. If the electro-magnet did not almost instantly respond to the current, and quite as instantly lose its magnetism at the moment the current ceased, then it would keep the armature attracted to its poles for an appreciable time. We should thus have a succession of claps from the hammer on the bell instead of the well known "dirl" due to the rapidly succeeding attractions on completing the circuit and disengagements on breaking the same.

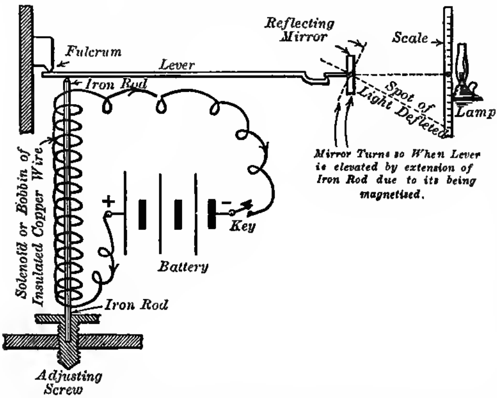


EDISON-HOPKINSON DYNAMO, SHOWING SHORT ELECTRO-MAGNET.

Alteration in the Length of Iron when Magnetised.—The late Dr. Joule of Manchester, the discoverer of "*the Mechanical Equivalent of Heat*," was the first to observe that when a bar of iron is magnetised its length is increased. Mr. Shelford Bidwell has, however, proved quite recently that if the magnetisation is increased towards saturation, the bar not only ceases to expand, but actually diminishes in length below its normal size. He has also experimented upon other magnetisable substances, and in the case of the metal nickel he obtained greater contraction than in the case of iron, with even a comparatively weak magnetising force. To test this interesting phenomenon, arrange an iron rod vertically, and surround it by an insulated spiral conductor of copper wire connected up to a battery, through a key, as shown by the accompanying diagram. Fix the lower end of the iron rod into an adjustable footstep, and

COMMON FORM OF HOUSE ELECTRIC TREMBLING BELL, SHOWING ELECTRO-MAGNET, &c.

let the upper end bear on a light brass lever at a short distance from the fulcrum. Let the other end of this lever act upon a projection extending from the back of a horizontally-pivoted or tightly-suspended circular mirror. Place a lamp and scale in front of the mirror, or better still, project a beam of light from an electric arc lamp or a lime-light on to the mirror, and let the reflected spot of light be cast on the opposite wall of the room or on to a white screen. If the iron bar is lengthened by the magnetising influence of the current flowing through the coil of wire, then it will lift the lever and turn the mirror so that the spot is deflected downwards; but if you increase the current considerably, then the bar will contract owing to its increased magnetisation, thus lowering the lever and causing the mirror to deflect the reflected rays above the zero point of the scale. Physicists and electricians have not yet found out the exact reason for these expansions and contractions. All they do know or surmise is that the molecules of iron or other magnetisable metals are turned or twisted round on their axis when magnetised. Why the length of the bar should first expand and then contract is at the present time a mystery.



SHELFORD BIDWELL'S EXPERIMENT FOR EXHIBITING THE ALTERATIONS IN THE LENGTH OF IRON AND OTHER MAGNETISABLE METALS WHEN MAGNETISED.

Lecture XIV.—Questions.

1. What happens to a bar of soft iron if a strong current be passed through a wire held close above the bar and at right angles to it? What will now happen if the direction of the current be reversed?

2. Suppose you wind an insulated wire round a poker and send a strong electric current through the wire, what occurs? What will be the difference between the condition of the knob and of the other end of the poker? Give a sketch to illustrate your answer, showing the direction of the current through the wire, &c.

3. If you were given any battery cell you chose, wire with an insulating covering, and a bar of soft iron, one end of which was marked, state exactly what arrangements you would make in order to magnetise the iron so that the marked end might be a north-seeking pole. Give a diagram. (S. and A. Exam., 1887.)

4. A long copper wire covered with silk is wound several times round an iron rod. On connecting the ends of the wire, one with each terminal of a battery, the iron rod becomes a magnet. How does the direction of magnetisation of the iron (or position of its north-seeking and south-seeking poles) depend upon how the copper wire is wound, and which end of it is connected with the copper or + end of the battery? Give a drawing. (S. and A. Exam., 1885.)

5. An insulated copper wire is wound round a glass tube, AB, from end to end, and a current is sent through it, which to an observer looking at the end A, appears to go round in the same direction as the hands of a watch. A rod of soft iron is held (1) inside the tube; (2) outside but parallel to the tube. What will be the magnetic pole at that end of the bar which is nearest to the observer in each case? (S. and A. Exam., 1888.)

6. A bar of iron is held vertically above and fair in line with the axis of a hollow solenoid through which a current is passing. What happens and why? Give a sketch marking the direction of the current through the solenoid, its poles, and also those of the bar. If the bar is now introduced until its ends are equally within or without the ends of the solenoid, what changes take place, if any, in the polarity of the bar and in its magnetic strength?

7. A rod of soft iron is placed upright on a table. Its upper end is surrounded by a coil of insulated wire which does not touch the rod. When a strong current goes through the wire, the iron rises in the coil. Explain this by sketches and index of parts. (S. and A. Exam., 1883.)

8. Sketch and describe by index how you would make a horse-shoe electro-magnet. Clearly indicate by arrows the direction of winding and direction of current in order to produce the required polarity.

9. Sketch and explain the action of an ordinary house electric bell. Why should you prefer to use a short electro-magnet for the same if you wished it to ring rapidly?

10. If you were asked to design an electro-magnet for a large gong which required to strike distinct separate signals, what form of electro-magnet would you employ, and why?

11. One end of a coil of wire, through which a current passes, is found to attract the north pole of a compass needle when placed at a certain distance from it. Will the action be the same (1) in nature, (2) in amount, when a rod of soft unmagnetised iron is placed inside the coil? (S. and A. Exam., 1890.)

LECTURE XV.

CONTENTS.—Action of a Force and the Reaction against it are always Equal and Opposite in Direction—Rotation of a Magnetic Pole Round a Current, and of a Current Round a Pole—Faraday's Apparatus for Exhibiting the Rotation of a Current-Carrying Conductor Round One Pole of a Magnet—The Automatic Twisting of a Current-Carrying Wire Round a Magnet—Questions.

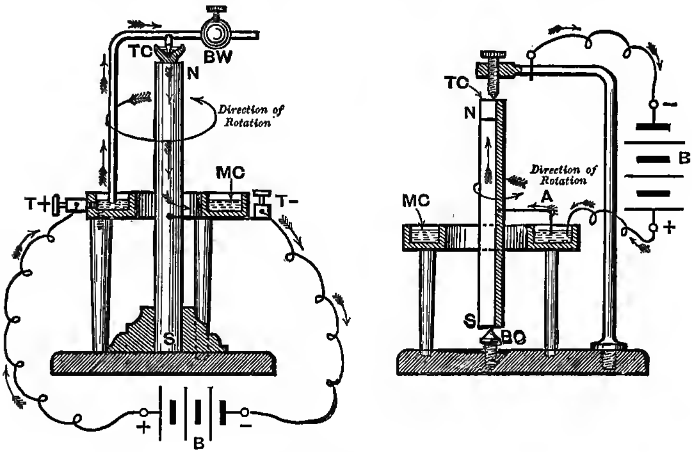
Action of a Force and the Reaction against it are always Equal and Opposite in Direction.—You know from ordinary everyday experience that if you hang a weight to the hook of a spring-balance, the spring reacts equally hard against the force exerted by the weight and in exactly the opposite direction. If you place a weight on the table or upon a graduated spring-balance, or float a ship in the water, or, in fact, apply a force anywhere and in any direction, you find a universal law in nature, that "*Action and reaction are always equal and opposite.*" We shall now apply this law to our previous experience regarding the action of a current on a magnet's pole.

Rotation of a Magnetic Pole Round a Current, and of a Current Round a Pole.—Referring back to the experiments in Lectures IX. and X., you there learned that the **N**-pole of a magnet always tends to rotate round a straight current-carrying wire in a certain definite direction, and that the **S**-pole equally tends to rotate round the same wire in the opposite direction. Now, reasoning from the axiom just stated, viz., that "*Action and reaction are equal and opposite,*" you obviously conclude that whilst the magnet's poles tend to rotate round the current, the current on the other hand must of necessity tend to rotate round the magnet's poles; and further, that it merely depends upon the arrangement of the apparatus which of them move (the magnet or the wire), or whether both move simultaneously.

We shall first of all explain the construction and action of Faraday's apparatus for exhibiting the rotation of a current round a pole.

EXPERIMENT XXI.—(1.) Arrange apparatus as shown by the *first* of the two following figures, and pass a strong current from the battery through the circuit in the directions indicated by the arrows.

You immediately find that the vertical current-carrying wire rotates in the direction indicated by the circular curved arrow. If you apply a sufficiently strong current, and your bar magnet is also strong, you will have no difficulty in obtaining a speed of over one hundred revolutions per minute. Now reverse the direction of the current, or reverse the position of the bar magnet's



Faraday's Apparatus for Exhibiting the Rotation of a Current-Carrying Conductor Round One Pole of a Magnet.

Index to Parts.

NS	represents	N and S poles of a vertical magnet.
B	,,	Battery arranged to give a strong current.
MC	,,	Mercury cup of wood and of annular form.
T+, T−	,,	Terminals where current enters and leaves apparatus.
TC	,,	Top centre with mercury contact.
BW	,,	Balance-weight to current-carrying wire.
A	,,	Arm of copper wire soldered to the vertical magnet. It is fixed in the first case, and free to rotate with the magnet in the second case.
BC	,,	Bottom centre (adjustable) in second figure.
→, ⤻	,,	Direction of current, and curved arrows the direction of rotation in each case.

poles, and the wire rotates in the opposite direction. You naturally ask, "But how am I to reason out and to remember the precise direction of the current's rotation for any particular direction of current with respect to the **N** or the **S** pole of the magnet?" You will have no difficulty in doing so if you

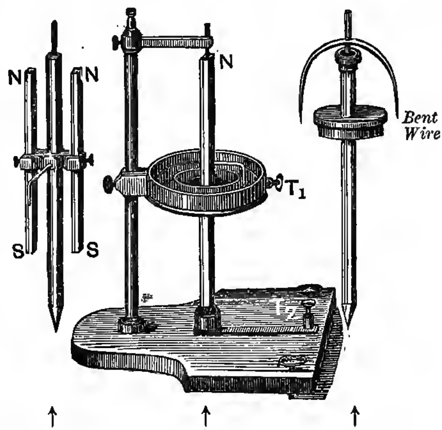
will first make a large figure of the precise arrangement of the several parts, and then plot down with dotted lines and arrow-heads the direction of the bar magnet's field and of the current's circular magnetic field around the current-carrying wire. You will remember that we have frequently shown that if a magnet were free to move in obedience to a current's field, the magnet would tend to so place itself that a maximum number of the current's magnetic lines of force passed through the magnet in the same direction as the magnet's own lines naturally flow *through itself*. Consequently, if the magnet be fixed but the current's conductor be free to move, the latter always tends to move into a position so as to confirm, and if possible to increase, the strength of the magnet. You also remember the RIGHT-HAND test which we have so frequently urged you to apply when the magnet was free to move. Now since the case of the current being free to move is just the very reverse of the magnet moving due to the reaction being directly in the opposite way to the action, we now ask you to *apply your* LEFT HAND *to the wire, with the palm of the hand placed thereon facing the fixed magnet, which is on the opposite side of the wire, and with the four fingers in the direction of the current's flow along the wire, then the outstretched thumb will indicate the direction of the rotation of the current-carrying wire.* Sketch a left-hand, as just directed, in your figure of the apparatus, and you will find that you cannot fail to remember the result of the above conclusions, which have been arrived at from reasoning out the directions of the two forces in action, viz., the force due to the magnetism of the bar and that due to the current's field.

(2.) Arrange your apparatus as shown by the second of the last two figures. Here the vertical broad bar magnet, instead of being fixed, is free to rotate on its magnetic axis. The current is this time conveyed from the centre up the sides of the magnet and past each side of the N-pole. Apply your LEFT HAND to either edge of the magnet, with the fingers pointing in the direction of the current's flow and the palm facing the N-pole; then your outstretched thumb at once reveals the direction in which rotation will take place. Reverse the magnet, or reverse the current's direction, and immediately the rotation is reversed.*

* Messrs. Eadie and Nicol, two of the author's day-students, have just made from the last figure a large working model to illustrate this experiment. With a magnet ¼ inch thick, 2¼ inches broad, and 14 inches long, they obtained thirty-nine revolutions per minute, with about thirty amperes of current. They fixed a ½-inch metal V mercury cup to the top of the magnet, and a Λ brass centre for the bottom centre to bear against, which obviated the necessity of boring holes in the ends of their magnet.

The student will at once understand the reason for not passing the current (in the last experiment) throughout the whole length of the magnet when we remind him that the action of the two poles being equal and opposite upon the current's field, no motion could take place; therefore the action and reaction must be confined between one pole and the current.

The following figures illustrate the form in which apparatus is generally made and sold by electrical instrument-makers for exhibiting the effects which we have just discussed. The middle figure shows the adjustable stand with annular mercury cup, and the vertical magnet with radial bent arm of copper wire, as in the last experiment. The current is, however, conveyed along the lower half of the magnet between the terminals T_1 and T_2, instead of by the upper half. This magnet may be easily removed and replaced by the two bar magnets with central spindle shown by the left-hand figure, when it is desired to illustrate the rotation of the poles of a magnet round a current. These two magnets rotate within the central hollow of the annular mercury cup, and they may be placed with both **S**-poles or with both **N**-poles downwards, or again with the polarity of the poles in opposite directions, in which case no motion will take place if the poles are of equal strength and the current flows equidistant from each of them. On the right hand is shown another form of apparatus to be placed in the fixed stand. Here you see a central fixed vertical bar magnet topped by a free or movable semicircular conductor or bent wire, whose ends dip into the annular mercury cup when the latter is sufficiently elevated and fixed on its support. The current in this case divides along the two forks of the bent wire, and thus produces a couple or double



FOR ROTATION OF POLES ROUND A CURRENT. FOR ROTATION OF CURRENTS THROUGH A MAGNET ROUND ITS N-POLE. FOR ROTATION OF DIVIDED CURRENT ROUND A POLE.

force tending to cause the forks to rotate round one pole of the magnet.

Such rotation arrangements may be varied in many ways. The production of different forms of them was a great source of interest and enjoyment to Faraday, since they enabled him to test the conclusions which he had arrived at after patient thought and much study. The most beneficial practical outcome of their application has been the dynamo-motor, by which means any good dynamo-generator may be used for the conversion of electrical into mechanical energy.

Sources of power, such as waterfalls and coalpits situated far from busy centres of industry, may thus be utilised by, first, the conversion of mechanical power (through the agency of water-wheels or steam-engines and dynamos) to that of electrical energy, this energy being conveyed for miles, if need be, along well-insulated conductors; and at the very spot, and to the required amount the electrical energy may be again distributed and converted into mechanical energy, thus enabling artisans of all kinds to work at their special calling in their own homes, instead of having to congregate in some large factory where power has been concentrated by the adoption of great steam-engines and long lengths of power-absorbing shafting. The extension of this form of the distribution of motive power is only in its infancy in this country, but in America and on the Continent many wonderful applications and adaptations of its capabilities have already been put into action.

The Automatic Twisting of a Current-Carrying Wire Round a Magnet.—EXPERIMENT XXII.—There is one very interesting modification of the foregoing experiments which was suggested some time ago to the author, but which he has not noticed in any text-book. Upon trying it before his class, he found that it worked admirably, and it is a very striking experiment.

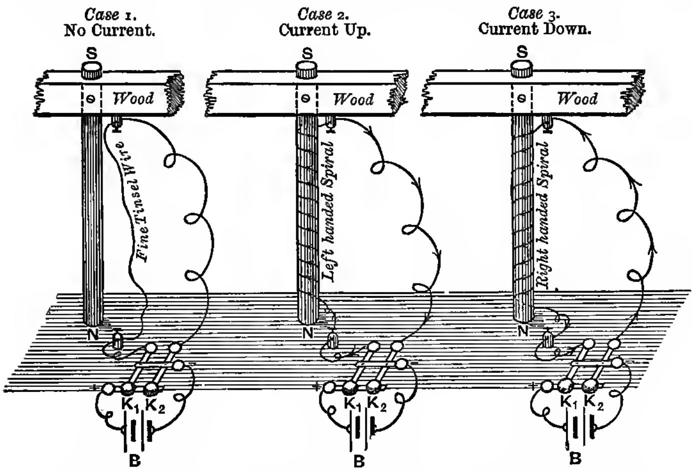
Referring to Case I in the next figure, you will observe that a cylindrical bar magnet is suspended in a vertical position from a wooden beam or other convenient support. A long fine flexible tinsel wire (such as is frequently used to adorn the grates of fireplaces in the summer-time) is suspended from a terminal screwed into the wood, and the lower end of the tinsel is connected to another terminal fixed near to the lower end of the vertical magnet. These terminals are connected up through any convenient form of reversing key with a battery.* The tinsel wire in *Case* I is shown hanging quite loose alongside the magnet; in

* The reversing key may be dispensed with if one is not at hand, and the connecting wires simply held on to the terminals of the battery and reversed between its poles at pleasure.

fact, the wire is what is called "dead," since no current is passing through it.

Case 2.—Depress K_1, so as to send a current upwards through the tinsel wire; it instantly becomes "alive," and twists itself rapidly round the magnet in the form of a beautifully defined left-handed screw-thread.

Case 3.—Now relieve K_1 and depress K_2; immediately the tinsel untwists from the magnet, and then twines itself on again in the form of a right-handed screw-thread. The whole operation takes place so rapidly that a few pieces of white tissue-paper should be fixed to the tinsel wire in order to render the movements more apparent. The experiment may be enjoyed by a large audience.



AUTOMATIC TWISTING OF A CURRENT-CARRYING WIRE ROUND A MAGNET.

N.B.—*The lower end of the magnet is several inches clear from the table.*

To foretell the directions in which the flexible wire will twist around the magnet, all you have to do is to hold your *left-hand* palm on this wire, as previously directed, with the fingers in the same way as you intend to pass the current, when the outstretched thumb will point towards the direction; or you may apply your right hand across the magnet, as directed at the end of Lecture XIII., and this will foretell the way in which the current must flow along the tinsel wire when it forms a right- or left-handed spiral around the magnet, for the current must flow so as to increase the magnetism of the magnet, *i.e.*, the lines of force through the magnet and the current's magnetic lines always tend to flow in the same direction, and thus mutually assist each other

Lecture XV.—Questions.

1. What is meant by the expression, "Action and reaction are equal and opposite," as applied to forces? Give illustrations with sketches.

2. How could you prove that the north pole of a magnet will revolve in one direction, and the south pole in the opposite direction, round a current-carrying wire? How could you predict the directions in each case? Give complete sketches.

3. Sketch Faraday's apparatus for demonstrating that a continuous current will revolve round one pole of a bar magnet, and describe its action by arrows, &c. If the current is reversed, what takes place, and why?

4. A vertical fixed magnet with its north pole pointing upwards, supports an Γ-shaped wire free to rotate around and parallel to the magnet. (*a.*) If the lower end of the wire dips into an annular mercury trough placed at the foot of the magnet, and a current be sent straight up the magnet from the **S** to the **N** pole, and then down the vertical leg of the Γ, what will happen, and why? (*b.*) If half of the vertical leg of the Γ be now cut away, and the mercury cup raised until its lower end again dips into the mercury and the current reapplied, what will happen, and why? (*c.*) If the current is then reversed, what will happen, and why? Give sketches illustrating your answers in each case.

5. A very flexible wire is hung loosely alongside of a vertical bar magnet. A current is passed down this wire. What will happen, and why? The current is stopped and then reversed. What will happen, and why? Give sketches.

6. A current is passed along a long, cylindrical, permanent magnet. What reasons can you give for supposing that the current will take a spiral course along the bar? In making your sketch to illustrate your answer, mark the **N** and **S** poles of the magnet and the direction of the spiral, *i.e.*, indicate whether it is the same as a right- or a left-handed screw-thread.

7. A circular coil is suspended in a vertical plane by two long, flexible conductors joined to the ends of the coil. A bar magnet is presented (*a*) horizontally, with one end towards the centre of the coil; (*b*) horizontally, with the magnetic axis of the magnet parallel to the horizontal diameter of the coil; (*c*) vertically, with the magnetic axis of the magnet parallel to the vertical diameter of the coil. Sketch what will happen to the coil in each case when a strong current is passed through it.

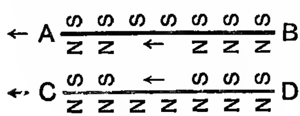
8. Sketch and describe how a freely-suspended vertical coil of wire traversed by a current would place itself if suspended between the poles of a horse-shoe magnet.

LECTURE XVI.

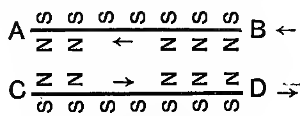
CONTENTS.—Electro-Dynamics—Ampère's Laws—Action between Parallel and Inclined Currents—Ampère's Stand—The Jumping Spiral, and other Apparatus for Illustrating Ampère's Laws—Questions.

Electro-Dynamics.—You are now in a position to study this part of the science which is concerned with the force which one current exerts upon another, termed *Electro-dynamics.* This section of electro-magnetism was first demonstrated and developed by a French philosopher named Ampère in 1821, shortly after Oersted's discovery of the action of a current on a magnet. If you bear in mind that a current always produces around its wire path a circular magnetic field of definite polarity, you will have no difficulty in resolving Ampère's Laws into the simple manifestations of attraction between unlike poles, and repulsion between like poles. We shall only give two of Ampère's Laws here in our own words, and then proceed to prove them by experiment.

Ampère's Laws—Action between Parallel and Inclined Currents.—LAW I.—*Parallel currents, if in the same direction, attract one another; and if in opposite directions, they repel one another.*



ATTRACTION BETWEEN AB AND CD.



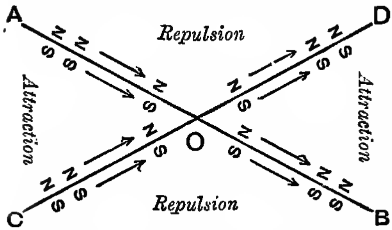
REPULSION BETWEEN AB AND CD.

LAW II.—*Currents whose directions are inclined to each other at any angle,* ATTRACT *each other if they both flow either to or from the vertex (or crossing point) of the angle, and* REPEL *each other if one flows towards and the other from the vertex.*

Or, *two currents crossing one another tend to move into a position in which they are parallel and in the same direction.**

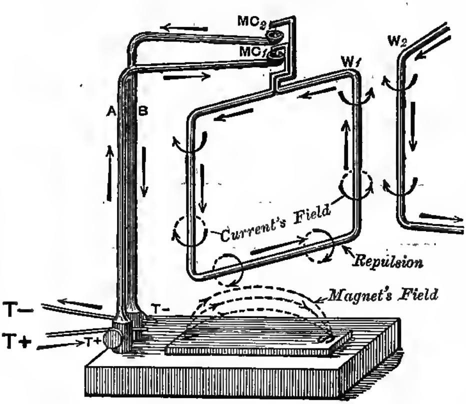
* As shown by next figure, if either AB or CD, or both, are free to move, then they will become parallel under the action of the currents flowing through them. See footnote to p. 116 for caution *re* N and S polarity.

EXPERIMENT XXIII.—In order to demonstrate these Laws, Ampère devised a simple piece of apparatus known as Ampère's Stand, which we illustrate by the following figure. It consists of a wire bent into the form of a rectangle, with its free ends terminating in fine points, one pair above the other, and each dipping into separate mercury cups, MC_1, MC_2, so that a vertical line through the centre of gravity of the rectangle passes through them. By this means the ▭ -shaped wire can be freely moved to the right or to the left without fear of breaking the circuit of the electric current, which flows from a battery to terminal T +, up the vertical rod A, entering the rectangle by MC_1, and leaving it by MC_2, whence it finds a path back to the battery by the vertical rod B and terminal T −.



ATTRACTION BETWEEN AO AND CO, ALSO BO AND DO. REPULSION BETWEEN AO AND OD, ALSO CO AND OB.

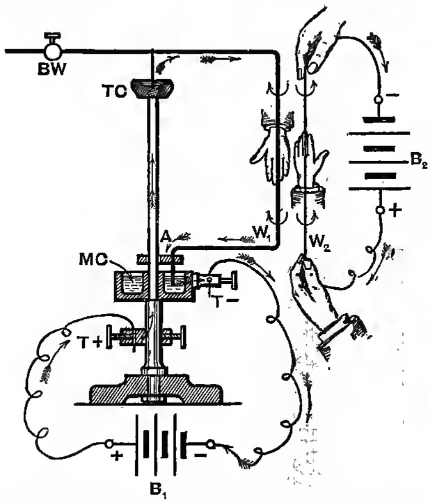
We have intentionally shown a bar magnet lying on the base of the stand in order to bring first of all to the student's recollection the action between a movable current-carrying wire and a fixed magnet. The current as it flows in the lower *horizontal* portion of the rectangle causes the wire to turn round at right angles to the axis of the magnet, in virtue of the action and reaction between the current's field in this part of the wire and the magnet's field. *Now remove the bar magnet*, set the plane of the rectangle fair with the centre line of the base-board, and bring forward a straight current-carrying-wire. Hold it parallel to the right-hand vertical side of the rectangle (as shown by the figure). If the currents flow as depicted, you



AMPÈRE'S STAND FOR DEMONSTRATING AMPÈRE'S LAWS.

will find *repulsion* takes place in accordance with Ampère's First Law, as indicated by the turning round of the rectangle. If you, however, place the wire which you hold upside down (or reverse the direction of the current in this wire), then *attraction* takes place between the two parallel currents, because they are in the same direction.

The following diagram is an improved form of Ampère's Stand



IMPROVED FORM OF AMPÈRE'S STAND, SHOWING REPULSION BETWEEN OPPOSITELY DIRECTED PARALLEL CURRENT-CARRYING-WIRES, W_1 AND W_2.

INDEX TO PARTS

B_1, B_2	represent	Batteries No. 1 and 2.
$T+T-$	,,	Terminals connected to the + and − ends of B_1.
MC	,,	Mercury cup of annular form, made of wood.
A	,,	Arm which is free to rotate with W_1.
W_1, W_2	,,	Wires No. 1 and 2.
TC	,,	Top centre or cup contact, filled with mercury.
BW	,,	Balance-weight to wire No. 1.
→	,,	Directions of currents.
⤷	,,	Directions of current's fields.
☞	,,	Hand-test for polarity or direction of current's field.

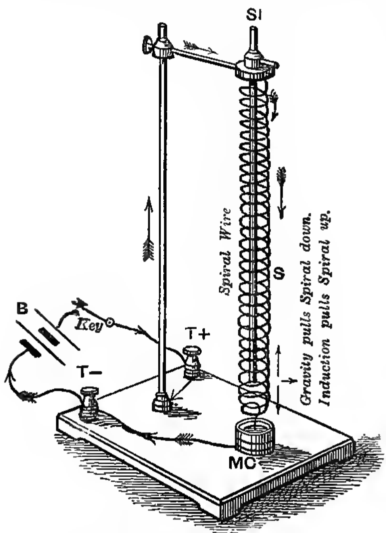
for demonstrating his First Law, since it permits of the current-carrying-wire rotating completely round about the central vertical support.

In the above figure, if you place your RIGHT HAND as shown

(with the palm in each case facing the reader), you cannot fail to observe that there exists between the two parallel current-carrying wires the same electro-magnetic polarity; or, in other words, *the directions of the two fields oppose each other.* However, reverse the direction of the current in W_2, and you at once get attraction, because the fields now offer **N** and **S** poles towards each other. Test this again, by aid of your RIGHT HAND properly placed on each of the wires, and you again confirm your belief in our rule, *thus obviating all necessity for committing to memory Ampère's First Law.*

EXPERIMENT XXIV.—A very striking and simple experiment, which confirms the first part of the First Law, is illustrated by the following figure.

The figure is self-explanatory. On closing the key, a current flows from the battery, B, to the positive terminal, T +, then up the vertical stand rod and down the whole length of the open spiral of steel or hard copper wire, S, into a mercury cup, MC, returning by the horizontal base-board connection to the negative terminal, T −, and thence back to and through the battery. Each successive turn of the spiral carries a parallel current in the *same* direction. The consequence of this naturally is, that opposite current poles, **N** and **S**, are induced between every two turns, causing such a strong combined attraction that the whole spiral contracts and the lower end of the wire is lifted out of the mercury. This breaks the circuit and cuts off the current. Gravity, now unopposed, reasserts herself, and pulls down the spiral to its normal length, thereby again completing the circuit. The wire thus keeps on jumping automatically up and down, creating a big electric flash at the mercury cup each time the circuit is broken. This jumping action is considerably augmented by putting a soft iron rod, SI, down the centre of

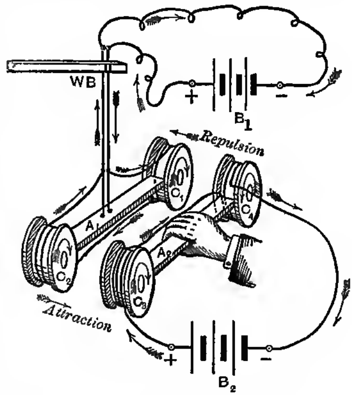


AMPÈRE'S FIRST LAW, ILLUSTRATED BY ROGET'S JUMPING SPIRAL.

the spiral (as shown by the figure), since it concentrates and intensifies the magnetic field between the different wire circles.

EXPERIMENTS XXV.—Just one more proof of Ampère's First Law, and then we will turn to his Second Law. Arrange the apparatus as illustrated by the annexed figure. Hold the wooden arm A_2, and present the coils C_3, C_4, fairly opposite to C_1, C_2. *Attraction* takes place between C_2 and C_3, while at the same time *repulsion* takes place between C_1 and C_4.

Sir William Thomson has devised a complete set of Standard direct-reading Electric Balances upon this principle, which measure from $\frac{1}{100}$ to 2500 amperes.*



APPARATUS FOR TESTING AMPÈRE'S FIRST LAW.

INDEX TO PARTS.

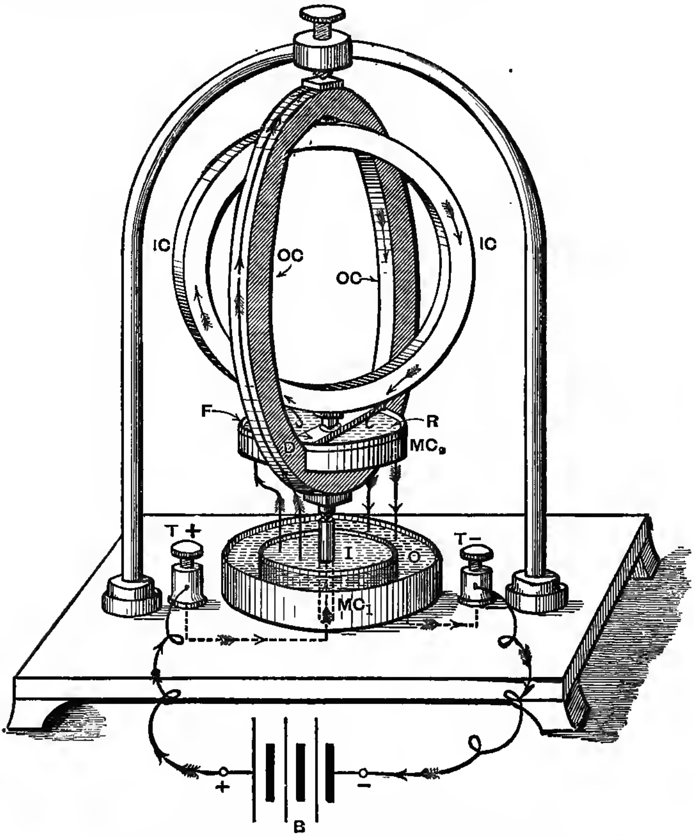
B_1, B_2, for Batteries.
C_1, C_2, „ Coils in circuit with B_1.
C_3, C_4, „ Coils in circuit with B_2.
A_1, A_2, „ Arms of wood.
WB, „ Wooden beam supporting C_1, C_2, by two flexible wires.
→ „ Direction of currents.

Referring to the first figure of Ampère's Stand (see Experiment XXIII.), remove the bar magnet from the base board, and hold the straight part of wire W_2 *horizontally* under, but at *any* angle with the lower horizontal side of the rectangle W_1. Immediately W_1 swings round until it lies parallel to W_2 (just as a freely-suspended horizontal bar magnet would do if placed over another horizontal bar magnet), thus proving Ampère's Second Law. Here, again, you have no necessity for committing this law to memory, for all you have to do in order to predict the result is to place your RIGHT HAND upon each of the wires in turn (as previously directed), and you cannot fail to realise how these two current-carrying wires will tend to become parallel owing to the natural *attraction* between the **N** and **S** poles, and at the same time the natural *repulsion* between the **N**←→**N** and the **S**←→**S** poles of the two fields. Many practical testing instruments have been devised upon this principle, such as Siemens' electro-dynamometer, &c.

This Second Law may be very prettily demonstrated by the following cleverly-designed instrument. Its construction will at

* For a description of these instruments and how to use them, see Rankine's "Rules and Tables," 7th edition, 1889, p. 398, and Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables," 6th edition, 1889, p. 82.

once be understood by comparing the drawing with the "Index to parts." Its action is as follows :—



APPARATUS TO ILLUSTRATE AMPÈRE'S SECOND LAW.

B represents Battery.
T +, T −, ,, Terminals.
MC_1, MC_2, ,, Mercury contacts.
I, O, ,, Inner and outer cups of MC_1.
D ,, Division of wood to bottom of MC_2, which acts as a commutator,* and changes the direction of current in IC every time it passes D.

F, R, represent Forward and return sides of MC_1, or *vice versâ* if B.'s current reversed.
IC, OC, ,, Inner and outer coils, both being free to rotate on their vertical axes.
→ ,, Directions of currents.

* Any device which changes the direction of a current in a circuit is called a commutator.

The current from the battery, B, flows *independently* through each of the coils, OC and IC. The ends of the outer coil, OC, dip down into the inner, I, and outer, O, cups of the lower mercury trough, MC_1, whereby the coil receives a *continuous* current. Two wires also dip into I and O from the upper mercury contact trough, MC_2, which is subdivided into two distinct parts by an insulating division, D. The current in this inner coil, IC, is thus *broken* and then *reversed* every time its dipping ends pass this division,* but the momentum of the coil carries it over this "dead point" or the position of equilibrium between the two current fields when the coils are in the same plane. You obtain in this way *continuous* rotation of both coils in *opposite* directions.

The student should draw a plan of the above coils showing their positions for different stages of their revolutions, marking with arrows and RIGHT HANDS (properly placed) the directions of the currents, their fields, and the attraction or repulsion (as the case may be) between the forces. By so doing he will render himself quite independent of requiring to remember Ampère's Laws.†

* The mercury is filled into the sides F and R of MC_2 until it rises a little above the division D. In the drawing the division is shown a little above the mercury, to assist in understanding its construction.

† The author has intentionally drawn the above figure to a large scale in order that it may serve as a working drawing to those teachers and students who may desire to construct the apparatus. Eight to ten times the above size would make a splendid model for lecture purposes. He is indebted for the idea and description of this interesting model to Professor George Forbes' Course of Lectures on Electricity, delivered before the Society of Arts, London, in 1886, and now printed in book form by Messrs. Longmsns, Green, & Co.

Lecture XVI.—Questions.

1. What is meant by the term "electro-dynamics"? Who first investigated the action of currents upon each other, and when?

2. State Ampère's First Law? Sketch in section an improved form of Ampère's Stand, and describe how you would use it in order to prove that parallel currents in the same direction attract, and in the opposite direction repel, one another.

3. A long spiral of stiff copper wire is hung vertically from a support, so that its lower end just dips into a pot of mercury. A strong current is sent through the spiral, what happens and why? Give a complete sketch.

4. Will the action you describe in answering Question 3 be automatic and continuous so long as the current is applied to the circuit? What would be the effect of reversing the current through the spiral? What effect, if any, would there be on introducing an iron rod down the axis of the spiral? Give complete sketches.

5. State Ampère's Second Law. Sketch and describe any form of apparatus known to you by which you could clearly demonstrate this law.

6. Show how by the simple application of "the RIGHT-HAND aid to memory" you can dispense with the committing to memory Ampère's Laws, and instead reason out for yourself and predict the directions in which attraction or repulsion between current-carrying wires must take place, however they may lie towards each other, and in whatever directions the currents may flow through them.

7. A coil of wire, free to turn on a vertical axis, is suspended within a fixed coil. A current is sent through both coils. How will the inner one turn, and why? Give a sketch.

LECTURE XVII.

CONTENTS.—Electro-Magnetic Induction—Currents Induced in a Closed Circuit by the Motion of a Magnet in its Vicinity, or *vice versâ*—Currents Induced in a Closed Circuit by the Motion of a Current-Carrying Coil in its Vicinity, or *vice versâ*—Different Directions of the Induced Currents on Approach and Withdrawal of a Secondary Circuit Moving in the Primary Field—Induced Currents in a Closed Secondary Circuit on Making or Increasing, and on Breaking or Diminishing, the Primary Current—Table of Induction Currents—Faraday's Law—Lenz's Law—Electro-Motive Force, Resistance, and Current—Comparative Statements of the Forces, Resistances, and Currents, Illustrated by Hydraulic and Electrical Circuits—Ohm's Law—Questions.

Electro-Magnetic Induction.—Just ten years after Ampère demonstrated the mutual action of electric currents, Faraday (in 1831) discovered that the motion of a magnet, or the motion of a current-carrying wire, in the vicinity of a closed circuit (or *vice versâ*), produced electric currents in the latter. This action of a magnet or current in inducing secondary currents has been termed *Electro-Magnetic Induction.**

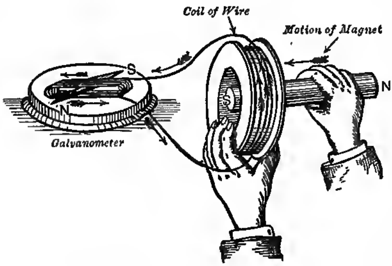
The phenomena of the induction of currents by magnets and currents form perhaps the most interesting as well as the most valuable branch of the study of current electricity or electro-kinetics (electricity in motion), since not only the Telephone, the Dynamo, and the Transformer (or Induction Coil), but also many other useful inventions for the practical application of electricity, have lately been produced, which for the most part depend directly upon this discovery by Faraday.

We shall first illustrate a few of Faraday's experiments, at the same time endeavouring to render the actions which take place clearer by the assistance of the knowledge already gained by the student in the previous Lectures; then state Faraday's Law, and finally explain what is meant by "Difference of Potential," and

* *Electro-Magnetic Induction.*—If any conductor forming a closed circuit is placed in a magnetic field, either wholly or in part, and if *any part* of that circuit is made to move so as to cut across or traverse lines of magnetic force, an electro-motive force is set up in that circuit. This action is called *electro-magnetic induction.* If the originating cause of a current is the movement of a conducting circuit in a magnetic field, such current is called a *magneto-electric current.*—DR. J. A. FLEMING.

the "Electro-motive force," which causes the flow of electricity along a closed circuit.

Currents Induced in a Closed Circuit by the Motion of a Magnet in its Vicinity, or ***vice versâ.*** —EXPERIMENT XXVI.—Take a bar magnet in your right hand, and a coil of fine insulated wire (of many hundred turns) in your left hand. Let this coil be connected up in circuit with a sensitive galvanometer * placed at least ten feet away from the magnet, so that the motion of the latter may not *directly* affect the needle of the former.



CURRENT INDUCED IN A CLOSED COIL BY THE MOTION OF A MAGNET.

First, Approach and introduce one pole of the magnet suddenly through the central opening of the coil. You observe a momentary deflection of the galvanometer needle to one side, followed by an immediate return to zero, thus indicating that a transitory current of electricity passed through the coil and galvanometer *circuit*.

Second, Withdraw the magnet quickly to a distance from the coil, and you observe that the galvanometer needle swings round to the *other* side of zero, and then at once comes back to zero again, thus indicating that a second current of short duration has been induced in the coil, but this time in the opposite direction to that when the magnet approached and passed into the coil. Now hold the magnet steady in your right hand, and suddenly bring forward the coil over the magnet, or approach both of them towards each other, and you observe the same effect as in the *first* case. Withdraw the coil from the magnet, or withdraw them simultaneously from each other, and you observe precisely the same effect as in the *second* case. It does not, therefore, make the slightest difference to the *direction* of the induced current whether the magnet approaches the coil or the coil the magnet; so long as their relative direction of motion is the same, the effect is the same. You cannot, however, help observ-

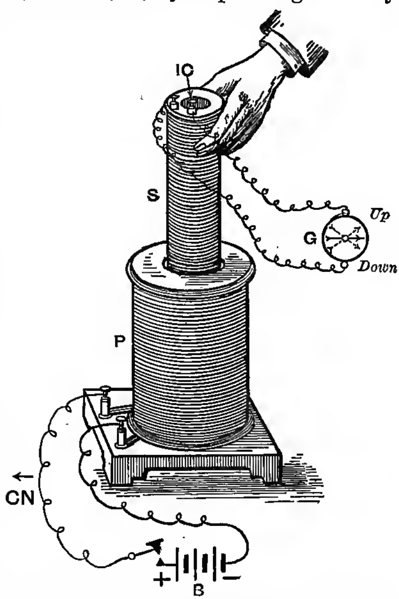
* The style of galvanometer shown by the above figure is of the ordinary detector pattern, which we described in Lecture X. as not being sensitive; yet by making it with a large number of turns of wire and a long needle delicately poised, the author finds that he can carry out this experiment so that it can be seen by a large class. Of course, a Thomson's mirror galvanometer of long range, with the spot projected on the wall of the class-room, and the gas-lights partially turned down, is more impressive.

ing a marked difference in the deflection of the needle (to the right as well as to the left) when the coil and magnet are brought together or separated *quickly* or *slowly*. In fact, if you bring them together very slowly, you will produce scarcely any perceptible deflection; whereas, if you do it very quickly, you may send the needle spinning round on its axis. Consequently, *the more rapidly the coil and magnet approach or recede from each other, the stronger will be the current induced in the coil.*

Currents Induced in a Closed Circuit by the Motion of a Current-Carrying Coil in its Vicinity, or *vice versâ.*—EXPERIMENT XXVII.—Arrange your apparatus as shown by the annexed figure, and close the *primary* circuit, P, by depressing the key. Watch the direction in which the compass-needle, CN, turns, so as to know the direction of the primary current through its solenoid. Now remembering that an electro-magnetic solenoid or current-carrying wire produces a magnetic effect equivalent to a magnet, you will have no difficulty in connecting in your mind the following results with those of the last experiment:—

First, Suddenly *approach* the secondary coil, S, towards one end of the primary coil, P, and you observe the galvanometer momentarily deflected (say) to the right or down. It then swings back to zero.

Second, Quickly *withdraw* the secondary coil from the primary one, and you notice the needle deflected to the left or up; and here again it immediately returns to zero. Precisely the same results as in the last experiment. Test the polarity of your primary coil, and if you so arrange the direction of the primary cur-



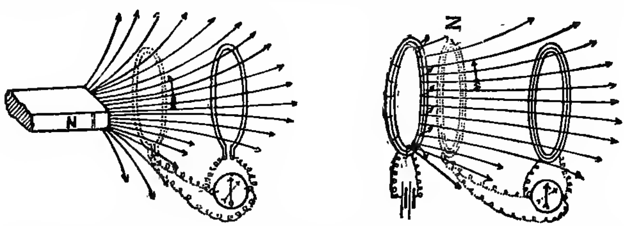
CURRENTS INDUCED IN A CLOSED COIL BY ITS MOTION NEAR CURRENT-CARRYING COIL.

INDEX TO PARTS.

B	for	Battery with key.
CN	,,	Compass-needle *under wire.*
P	,,	Primary coil.
S	,,	Secondary coil.
G	,,	Galvanometer.
IC	,,	Iron core.

rent that the upper end is a **N**-pole, the deflections will also coincide in direction with those of the previous experiment. Reverse the polarity of your primary coil by reversing the battery current, and the deflections of your galvanometer needle will be reversed from what they were before on approach and withdrawal respectively of the secondary coil. Test also the effect of bringing the secondary coil towards and away from the primary coil suddenly, and slowly, and you confirm the results previously obtained. Now insert a soft iron core, IC, into the secondary coil, and again try all the above experiments. The deflections are not altered in direction, but they are very much increased for the same rate of approach and withdrawal. You know the reason of this, for you have learned from previous experiments with solenoids and electro-magnets that a soft iron core concentrates the magnetic lines of force, and renders the field more intense within and close around it. In any case, you will understand the reason better after you follow our next experiment and explanation.

Different Directions of the Induced Currents on Approach and Withdrawal of a Secondary Circuit from the Primary Field. —Experiment XXVIII.—Looking at the two following figures, you observe (as you must have frequently observed before when examining the magnetic curves of magnets and solenoids) that



Figures Illustrating Direction of Induced Currents Due to Approach.

the lines of force are more closely packed together *close to* the end of a magnet or a current-carrying coil than they are at some distance from it. In other words, the field gets more and more intense the closer you get to the poles.

First, For the sake of explanation, let the pole *facing* the movable or secondary coil (to the right of each of the two figures) be a **N**-pole, and let the secondary coil be brought suddenly forward towards this **N**-pole in each case. Not only do you observe the deflections of your galvanometer needles are in the same direction, but you experience a greater resistance to the motion of the coil than you would do if the circuit was not closed,

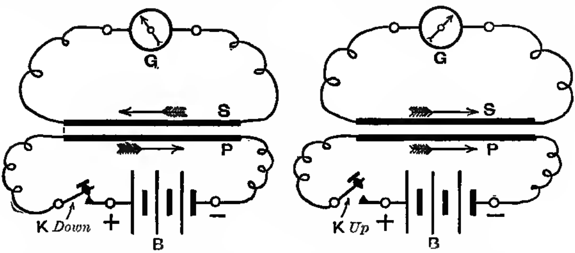
or if you moved it with the same rapidity through the air when no magnets or current-carrying coils were near it. There is an opposition to the force you exert when you move it in a strong magnetic field in the way represented by the above diagrams. Why is this? you naturally ask. Well, you remember that in bringing up a **N**-pole of a magnet towards another **N**-pole, or a **S**-pole towards a **S**-pole, or when bringing towards each other similar or like poles of electro-magnetic solenoids, you experienced a similar repulsive force against your efforts to bring them together. Consequently, you conclude that the current generated by induction in the secondary coil must be of such a direction as to produce a **North** or *like polarity on its leading side to that of the pole it approaches.* Therefore, by placing your RIGHT HAND on the secondary, with the outstretched thumb pointing in the direction of motion (that is, *towards* the locality of the **N**-pole or face to which your secondary coil approaches), *your fingers naturally point in the direction of the induced current* (as shown by the arrows on the dotted secondary coils).

Second, After the secondary coils have been brought close up to the **N**-poles of the magnet and the primary coil respectively, suddenly pull them away therefrom. You again experience a greater resistance than you would do when moving these secondary coils as quickly through the air, or as quickly from these poles if the circuits were not closed or complete. But you have often before experienced a similar opposing force when withdrawing the **S**-pole of a magnet or an electro-magnetic solenoid from the **N**-pole of another magnet or electro-magnetic solenoid. Consequently you conclude that the current now generated by induction in the secondary coil must be of such a direction as to produce a **South** or *unlike polarity on the side nearest the pole from which it is being withdrawn.* Again, place your RIGHT HAND on the secondary coils with the outstretched thumb pointing in the direction of motion (that is, *away from* the north face of the magnet or primary coil), and *your fingers naturally point in the direction of the induced current.* We need not here repeat the experiments with a **S**-pole of a magnet or of a primary coil facing the secondary coil, for the student will *at once* be able, from what we have just said, to determine for himself, by aid of his RIGHT HAND, the directions of the induced currents in cases of approach and withdrawal from the same. What you have to remember is this, that when you move a coil so as to increase the number of magnetic lines of force through it, your induced current *must* be of such a direction as to produce a *repelling* (*i.e.*, a *like*) pole to these lines, because you are forcing the coil *against* the field; and when you move the coil so as to diminish the lines of

force through it, your induced current *must be* of such a direction as to produce an *attracting* (*i.e.*, an *unlike*) pole to these lines, because you are forcing the coil *away* from the field.

Induced Currents in a Closed Secondary Circuit on Making or Increasing, and on Breaking or Diminishing, the Primary Current.

EXPERIMENT XXIX.—*First*, Take the cases of two parallel straight wires joined up as shown in the two following figures.*



INDUCED CURRENTS IN STRAIGHT PARALLEL CLOSED CIRCUITS.

(1.) *Close* the primary circuit, P, by putting *down* the key, K. A momentary current is observed, but in *the opposite direction* in the *secondary* circuit, S.

(2.) Suddenly *increase* the current in the *primary* (by switching on more cells), and again a momentary *inverse* current is observed in the *secondary*.

(3.) *Stop* the current in the *primary* by letting *up* the key. A momentary *direct* current is observed in the *secondary*, *i.e.*, in *the same direction.*

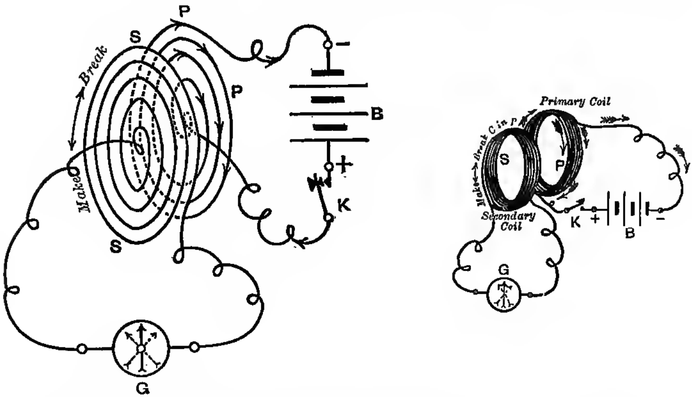
(4.) Close key, and suddenly *diminish* the current in the *primary* (by switching out some cells), and again a momentary *direct* current is observed in the *secondary.*

In Cases (1) and (2), by placing your RIGHT HAND *properly on* the primary *wire*, P, you observe that the *primary* current induces, as it were, **N**-polarity all along the side facing the secondary wire, S. In order that an induced current may be generated in the secondary wire, S, the current must therefore be of such a direction through it as to also produce a like or **N**-pole on the side facing the primary wire, for energy *must* be spent in opposing the generating of this secondary current. In Cases (3) and (4) energy has also to be spent in opposing the dying away or diminishing of

* The necessary galvanometer or detecting compass-needle has unfortunately been left out of the previous, the above, and the following primary circuits. It is useful, in doing the experiments, to show when the current (or its deflection) in the primary is in the same or in the opposite direction to that in the secondary circuit.

the primary current and its field; consequently the current induced in the secondary must present an unlike or **S**-pole along the face next to the primary wire.

Experiment XXX.—Instead of two straight parallel wires, take two flat or two cylindrical or solenoidal coils, as illustrated by the two following figures, and again perform the same four expe-



Figures Illustrating Induced Currents in Parallel Flat Coils and Cylindrical Coils.

Note the direction of the Current in the Primary, also the Induced Currents in the Secondary on making and breaking the Primary Circuit.

riments with the right-hand proofs as you have just seen done with straight wires.

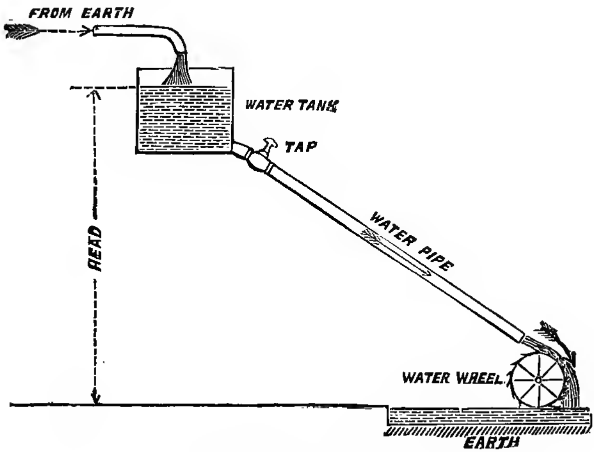
You will obtain precisely the same results, only the induced currents will be stronger for the same current strength in the primary, and distance between it and the secondary circuit. Put a piece of soft iron into the heart of each coil, and the induced currents will be still further increased, because the field is thereby increased in the coils.

The results of the foregoing experiments in this Lecture may be put down in tabular form as follows:—

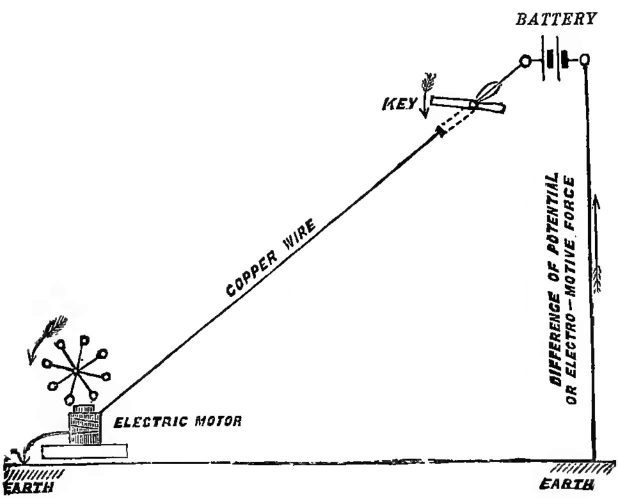
Table of Induction Currents.

Momentary **Inverse** Currents (*or opposing Like Facing Poles*) are Induced in a Secondary Circuit.	Momentary **Direct** Currents (*or attracting Unlike Facing Poles*) are Induced in a Secondary Circuit.
By (1) *Approach* to Primary. „ (2) *Starting* Primary Current. „ (3) *Increasing* Primary Current.	By (1) *Withdrawal* from Primary. „ (2) *Stopping* Primary Current. „ (3) *Decreasing* Primary Current.

We are now in a position to appreciate and (so far) to understand Faraday's Law and Lenz's Law. (*Read p. 156 before pp. 154 and 155.*)



THE FLOW OF A WATER CURRENT UNDER AQUA-MOTIVE FORCE THROUGH A PIPE.



THE FLOW OF AN ELECTRIC CURRENT UNDER AN ELECTRO-MOTIVE FORCE THROUGH A COPPER WIRE.

Comparative Statements of the Forces, Resistances, and Currents, Illustrated by the Two Previous Figures.*

Referring to the First Figure.

1. We show a Water System whereby on the turning of a tap or cock the circuit is closed, and a *Current of Water* issues from a tank or mechanically elevated source of mechanical energy,† due to the "head" or pressure or *aqua-motive force* possessed by the same above the position where it leaves the system for the earth, after having done work in turning the water motor.

2. The difference of level between the free or far surface of the water in the tank and the position where it leaves the water motor determines the *total* difference of pressure or "aqua-motive force" (due to the natural action of gravitational energy). It is this *total* difference of pressure which causes the fluid to flow through the tank and along the pipe, and turn the water motor with a definite *current strength.*

3. Now, *leaving out of the question the reaction due to the water motor, and supposing the water fluid to pass clear away from the lower or negative end of the pipe to the ground,* then the Current Strength or flow of water is *directly proportional* to the "head" or Total Difference of Pressure between the far end of the source of supply, and *inversely* proportional to the Frictional Resistance which this pressure overcomes in flowing through the tank and the pipe, or water-current conductor.

4. There is no pipe, however large or smooth, that it does not offer some frictional resistance to the flow of the water along it, and consequently reduce the total "head" or aqua-motive force. The rougher and smaller the pipe the greater the loss of head.

Referring to the Second Figure.

1. We show an Electrical System whereby on the turning of a key or switch the circuit is closed, and a *Current of Electricity* issues from a dynamo or battery or electrically elevated source of electrical energy,‡ due to the "potential" or pressure or *electro-motive force* possessed by the same above the position where it leaves the system for the earth, after having done work in turning the electric motor.

2. The difference of electrical level between the far end of the dynamo or battery and the position where it leaves the electrical motor determines the *total* difference of potential or "electro-motive force" (due to natural action of electrical energy). It is this *total* difference of pressure which causes the fluid to flow through the dynamo or battery along the copper wire, and turn the electrical motor with a definite *current strength.*

3. Now, *leaving out of the question the reaction due to the electrical motor, and supposing the electrical fluid to pass clear away from the lower or negative end of the copper wire to the ground,* then the Current Strength is *directly proportional* to the Total Difference of Potential between the far end of the source of supply, and *inversely* proportional to the Electrical Resistance which this pressure overcomes in flowing through the dynamo or battery and the copper wire or electric current conductor.

4. There is no electrical conductor so large or so good that it does not offer some electrical resistance to the flow of the electrical energy along it, and consequently reduce the total difference of potential or electro-motive force. The smaller and worse the conductor the greater the loss of electro-motive force.

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* Read each of the corresponding statements 1 and 1, 2 and 2, &c., in turn.

† Whether the mechanical energy be developed from an elevated tank of water, or a pump or any other means, does not much matter as far as our present comparison of the forces, &c., is concerned.

‡ Whether this electrical energy be developed from mechanical energy by the moving of a conducting circuit in a magnetic field, as in the case of dynamo machines, or from chemical energy by the burning of chemical substances in a battery, or by any other means, does not matter much as far as our present comparison of the forces, &c., is concerned.

Faraday's Law (1831).—*If any conducting circuit be placed in the magnetic field of a permanent magnet or of an electric current, then, if by either a change of relative position or a change of strength of primary current, a change is made in the number of lines of force passing through the* SECONDARY, *an* ELECTRO-MOTIVE FORCE *is set up in the* SECONDARY *proportional to the* RATE *at which the number of included lines of force is varying.*

Lenz's Law (1834).—*In all cases of* ELECTRO-MAGNETIC INDUCTION *the induced currents have such a direction that their reaction tends to stop the motion which produces them.*

Electro-Motive Force, Resistance, and Current.—You observe in Faraday's Law the expression "an Electro-motive Force is set up in the Secondary proportional to the Rate at which the number of included lines of force is varying." We would like you to understand the meaning of the term "Electro-motive force," and if possible the whole expression, although of course we cannot fully discuss this important subject in such an Elementary Manual as the present. We shall, however, frequently return to it, more especially in our Advanced Text-Book.

We shall not here attempt to carry further the comparison between the hydraulic and electrical systems. We however think it advisable to state Ohm's law, which expresses the above-mentioned relation between *Current strength* and the *Electro-motive force* * which keeps the current flowing through the *Resistance* which the force meets with in an electrical circuit.

$$\textbf{Ohm's Law,}\text{—Current} = \frac{\text{Electro-motive force.}}{\text{Total Resistance.}}$$

Or if C represent the Current, E the Electro-motive force, and R the total Resistance in circuit, then

$$C = \frac{E}{R}, \text{ or } E = C \times R, \text{ or } R = \frac{E}{C}.$$

Unfortunately, we have left no time or space to refer to the induction coils, dynamos, or transformers, whose principles of action depend so directly upon the fundamental experiments of Oersted, Ampère, and Faraday. We must now take up the construction and action of batteries.

* The terms electro-motive force and *total* difference of potential are synonymous. When we speak, however, of potential difference, we merely mean the difference of electrical pressure or *voltage* between any two points in the circuit, such as the potential difference between the ends of the copper wire conductor shown in the last figure. The term electro-motive force is reserved for the *total* difference of potential, or the force urging the current throughout the *whole* circuit.

Lecture XVII.—Questions.

1. What is meant by the term Electro-Magnetic Induction?

2. Sketch and describe an experiment to illustrate the induction of currents in a coil of wire joined up to a galvanometer when a magnet is moved towards, and away from, the axis of the coil. Suppose that you shoot the magnet *completely* through the centre of the coil at one stroke, explain what occurs, and why?

3. You have a metal hoop. Describe, and give a figure of, some arrangement by which, without touching the hoop, you could make electric currents pass round it first one way and then the other. (S. and A. Exam., 1882.)

4. Sketch and describe an experiment to illustrate the induction of currents in a secondary coil when it is moved towards and away from the end of a primary current-carrying solenoid. Why is the direction of the current different on approaching and withdrawing the secondary coil? Mark the directions of the primary and the induced currents in each case.

5. Why is the number of swings of a compass-needle considerably reduced by placing it in a metal box?

6. A piece of covered wire is passed a few times round a wooden hoop; its ends are joined up to a galvanometer. The ends of another piece of covered wire which is wrapped round a similar hoop are joined up to a battery. What will happen if the two hoops are (*a*) brought quickly near to one another, and (*b*) if they are quickly separated? (S. and A. Exam., 1879.)

7. How could you temporarily stop or weaken a current in a wire without disconnecting it from the battery, by means of the motion of another wire through which a current is passing? (S. and A. Exam., 1883.)

8. State Faraday's and Lenz's Laws.

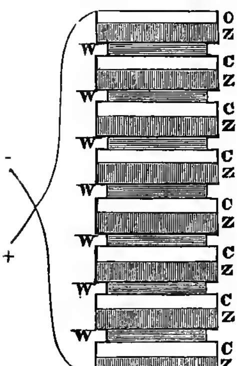
9. Draw a comparison (in your own words) between the flow of water through a pipe from a reservoir and the flow of electricity from an electrical source through a wire.

10. State Ohm's Law, and give your ideas of the meaning of the terms potential, electro-motive force, potential difference, voltage, electrical resistance and current.

LECTURE XVIII.

CONTENTS.—Historical Note on the Discoveries of Galvani and Volta, &c.—Volta's Pile—Origin of the Terms Voltage and Volt, &c.—Simple Voltaic Cell and its Chemical Action—Polarisation—Local Action—Amalgamation of Zinc Plates—Daniell's Cell and its Chemical Action—Finding the Fall of Potential through a Cell, and Measuring its Internal Resistance—Different Forms of Daniell's Cell—Grove's and Bunsen's Cells and their Chemical Action, &c.—Questions.

Historical Note on the Discoveries of Galvani and Volta, &c.—About the year 1780, Galvani, Professor of Anatomy at Bologna in Italy, whilst experimenting in his laboratory with a frictional electrical machine, observed that some recently skinned frogs, lying on a table near the machine, twitched convulsively whenever the machine was worked. Not long afterwards he noticed the same effect produced on several dead frogs which had been hung on an *iron* balcony by means of *copper* hooks, whenever the wind brought their legs into contact with the iron. He repeated these experiments, and concluded that at the junction of the nerves and muscles there is a separation of the two electricities (+ and −), the nerve being positively, and the muscle negatively electrified, and that the convulsive movements were due to the two electricities being connected by the metal hook and the iron balcony.

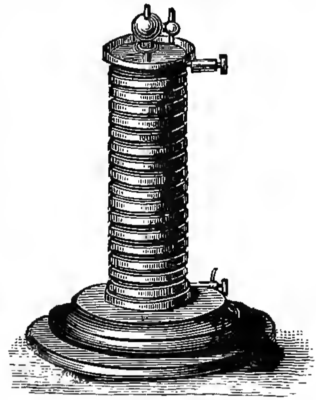


VOLTA'S PILE.

About 1800, Volta, Professor of Physics in the University of Pavia in Italy, investigated these effects more thoroughly, and showed by means of a delicate condensing electroscope * that the seat of the electrical energy lay in the contact between the two dissimilar metals (copper and iron), and that the frog's muscles and nerves simply served the purpose of completing the circuit, and of

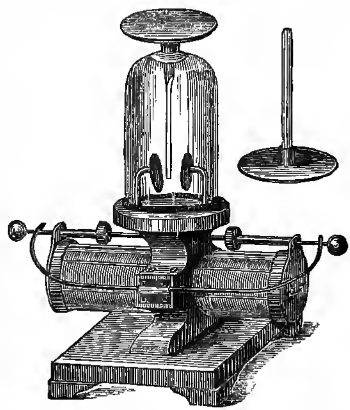
* This instrument and its action will be described when we come to Electro-Statics or Frictional Electricity, but, in the meantime, see the figure on the next page.

rendering the presence of the force visible by their contraction. He carried out a number of experiments, and finally produced what is known as the *Voltaic Pile.* This, as may be seen from the last and the next figure, consisted of discs of copper, C, and zinc, Z, with wet cloth or blotting-paper, W, moistened with brine; the object of the wet cloth, in his idea, being merely that it might act as conductor, and prevent contact between each two pairs of copper and zinc plates and the next pair.



VOLTAIC PILE AS NOW MADE WITH TERMINALS.

With such a pile, composed of a large number of pairs of discs of dissimilar metals, and the condensing electroscope, he excited considerable interest in the scientific circles of his day. He further discovered that by merely soldering together two bars of different metals, according as the one or the other was brought into contact with his condensing electroscope, the apparatus showed a free positive or a free negative charge.



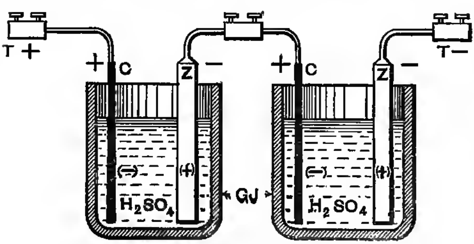
HORIZONTAL VOLTAIC DRY PILE WITH MOVABLE POLES AND CONDENSING ELECTROSCOPE.

Volta's next discovery was that it was not necessary for the pairs of metals to be brought into actual metallic contact with each other, but that even better results were obtainable by placing them side by side in a vessel containing some exciting liquid, such as dilute acid. Hence the simple voltaic cell illustrated by the next figure. For about forty years after Volta's discoveries, the *contact* of dissimilar substances, either actually or through some conducting medium, was regarded as the seat of electro-motive force of the cell, and therefore the cause of the current. Afterwards, however, owing to the researches of Faraday and others, a new school sprang up, which advocated the

chemical theory, *i.e.*, that the chemical action which goes on in the cell not only produces the electro-motive force, but keeps it up, so as to supply a continuous current therefrom. Now-a-days it is generally believed that both contact and chemical action together play an important part in giving us an electric current.

From this short historical note of the origin of the chemical method of producing electrical energy, you will understand why we adopted and still retain to this day the various terms GALVANIC battery, VOLTAIC cell, GALVANISM, and how the new term VOLTAGE (or potential difference maintained by a battery or a dynamo between any two points on a conductor, as measured in VOLTS) has been derived. It is customary to commemorate famous scientific discoverers by naming after them some apparatus, effect, or unit of measurement, with the inception of which, or through whose investigations, we are indebted for any important addition to our knowledge of appliances, phenomena, or laws. Hence the name AMPERE was given to the practical unit of *Current*, VOLT to the unit of *Electric-motive force*, and OHM to the unit of *Resistance*.

Simple Voltaic Cell.—If, in a glass or glazed stoneware jar three-quarters filled with dilute sulphuric acid in the proportions of 1 part concentrated acid to 10 parts water, you place a plate of *pure* zinc (Zn) and a plate of *pure* copper (Cu), as shown below, no change seems to take place in either the acid or the plates. You can, however, detect by the aid of a very delicate electrometer* that the free end of the copper pole is charged with positive (+), and the free end of the zinc pole with negative (−) electricity; and further, that there is a definite difference of potential between these points. Now, such a cell is capable of furnishing a continuous current of electricity; for whenever you join the ends of the copper and zinc poles

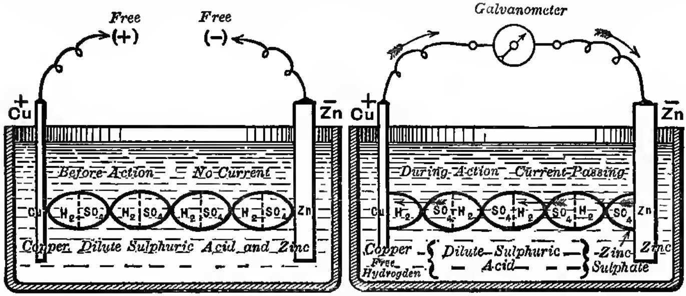


TWO SIMPLE VOLTAIC CELLS JOINED IN SERIES.†

* An *Electrometer* is any instrument for measuring differences of electrostatic potential between any two points.

† Cells are said to be joined in *series* so as to form a battery when the positive terminal or pole of one cell is joined to the negative of the next, and so on.

together through a galvanometer, you observe a *constant* deflection of the needle to one side, proving that a current flows in the outside circuit. Since it has been customary to consider the direction of a current as if it were from the positive to the negative, or from a higher to a lower potential (just as we regard heat as flowing along a conductor from a higher to a lower temperature), you naturally assume that the current is flowing from the copper to the zinc pole in the outside or galvanometer circuit. To ascertain which way the current flows through or inside the cell, place a very delicately poised magnetic needle immediately under or immediately over the cell, and with the aid of your RIGHT-HAND test (so frequently explained before) you find that the current is moving



SIMPLE VOLTAIC CELL, SHOWING THE ELEMENTS OF WHICH IT IS COMPOSED AND THE CHEMICAL ACTION WHEN THE CIRCUIT IS CLOSED.
The complete ovals denote molecules of dilute sulphuric acid.

from the zinc to the copper plate, or in the *opposite* direction to the flow outside the cell. If you keep the circuit closed for a sufficiently long time, you will further observe that the current becomes weaker and weaker, and if you take out the zinc plate for inspection, you will find that it has been considerably wasted, or eaten into, or burnt away, due to its forming zinc sulphate, $ZnSo_4$, with part of the sulphuric acid of the liquid.

Polarisation.—You will also see, shortly after the starting of the current, that bubbles of gas (which, if collected and tested, will be found to be pure hydrogen) collect at and rise up from the copper plate. In other words, the cell becomes *polarised.**

* This application of the term must not be confounded with the polarity of a magnet (see our definition of the latter, Part I., page 15). In the present case it simply means that the difference of potential between the *poles* of the two plates has been reduced by the deposition of the hydrogen on the copper plate, owing not only to a reduction of the area of action of the same, but also to the fact that hydrogen has an opposite electrical polarity, or is electropositive to zinc, and therefore tends to send a current from itself against the natural zinc-to-copper direction within the cell.

The cell, so long as it lasts, is a little chemical furnace, wherein zinc is burned to produce the current; but since the difference of potential does not keep constant, this form of cell is not used in the practical applications of electricity, such as telegraphy, telephony, and electric-bell circuits. It is, however, very useful upon an emergency in the class-room or laboratory, since it can be put together in a few minutes, and it serves as a stepping-stone to the understanding of the more complicated chemical actions in other cells. We wish you particularly to note the chemical changes which take place in the cell, as fully marked upon the second figure, and to remember them.

Local Action.*—There is another objection to the use of this cell (in fact, to all cells wherein zinc is used), viz., the difficulty of obtaining *pure* zinc. If ordinary commercial zinc be employed, it contains numerous impurities, such as particles of iron and carbon, to most of which zinc is electro-positive as it is to copper. Consequently, little local cells are set up between the zinc surface and these particles of foreign matter, thus causing what is termed local action and a necessary short-circuiting or closed-circuit between the zinc and iron or carbon, &c. The zinc plate in the localities where these are present is therefore burnt away all the more rapidly, and its capability of producing current for useful outside work reduced in consequence.

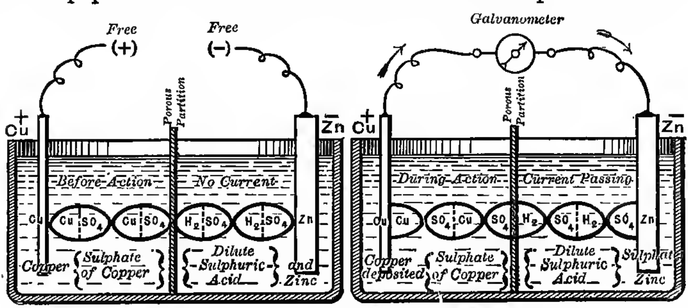
Amalgamation of Zinc Plates.—In order to prevent this local action and wasteful consumption of zinc, a common plan is to coat the plate with mercury before using it in the cells. This is effected by immersing the zinc in dilute sulphuric or hydrochloric acid for a few minutes to clean its surface, then by placing it in a dish of mercury with some of the acid, and finally rubbing the mercury over the zinc with a long-handled brush or cloth tied to the end of a piece of wood, but on *no account* with the bare fingers, as mercury is dangerous to the human system. This process produces a clean, uniform, homogeneous surface, but it has to be repeated as often as the mercury comes off. Another plan is that of pouring a small percentage of mercury into the zinc whilst it is in a molten condition, and before it is cast into the shape required for forming the plate.†

Daniell's Cell.—Hundreds of patents have been taken out with

* Local action often takes place from a want of perfect homogeneity of structure in the electro-positive plates, *i.e.*, there may be hard and soft pieces of zinc in the plate, one of which is naturally at a higher potential than the other. The greatest care is therefore necessary in the preparing of good plates to see that not only all foreign matter is absent, but that they are uniform in structure.

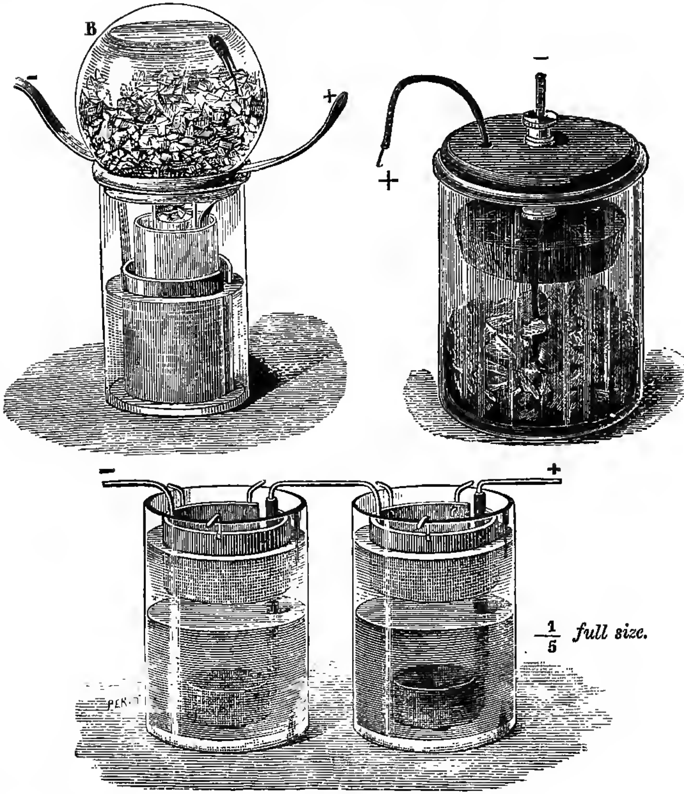
† See *The Electrician* of December 27, 1889, p. 185, for Smith's method of amalgamating storage battery plates.

the view of preventing polarisation, and of obtaining a better return in electrical energy for the zinc consumed in the production of the same. We have not space or time to describe more than three or four well-known and common kinds of cells, which have so far stood the test of time and experience that they are still in common use. Each has its special advantages, and although there are no doubt others quite as good, if not better, yet from an educational point of view their construction and action are not so simple, so that we must leave their description over to our Advanced Text-Book. One of these devices is known as the Daniell's Cell, of which there are many modifications. Some of these are illustrated on two following pages. In its simplest form it consists of a glass, stoneware, or other water-tight vessel not attacked by acid. A zinc and a copper plate form respectively the electro-positive and electro-negative elements or plates. Between them is placed a porous partition or division, most commonly of unglazed pottery, sometimes of millboard or a sheet of thick paper. On the zinc side of this division is put dilute sul-

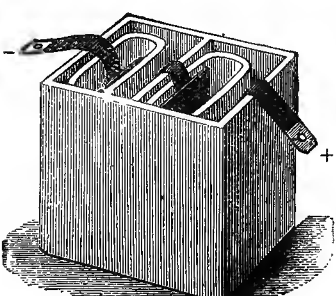


DANIELL'S CELL, SHOWING THE ELEMENTS OF WHICH IT IS COMPOSED AND THE CHEMICAL ACTION WHEN THE CIRCUIT IS CLOSED.

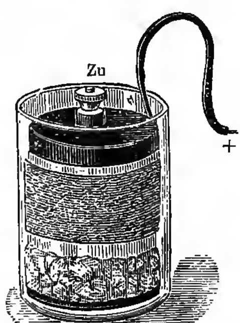
phuric acid (H_2SO_4), or perhaps a solution of sulphate of zinc ($ZnSO_4$), or even water itself alone, if the cell is not required for immediate use; and on the copper side, sulphate of copper ($CuSO_4$) dissolved in pure water, together with some sulphate of copper crystals (bluestone) to keep up the supply of copper, for the following reasons:—When the circuit is free or open, a free (+) charge is found at the copper pole, and a free (−) charge at the zinc pole, but no change takes place in the zinc and copper plates if they are perfectly pure. Endosmose and exosmose, or a slow creeping, mixing, and interchange of the sulphuric acid and sulphate of copper solutions, undoubtedly occurs, so that the cell cannot be left standing idle for even a few days without fouling, and thus reducing its electro-motive force.



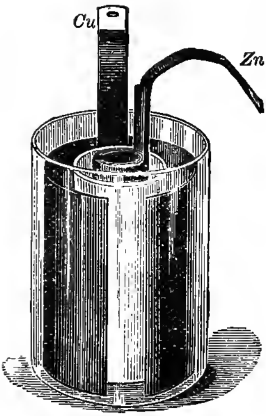
BREGUET'S BALLOON, ORDINARY, AND CALLAUD'S FORMS OF GRAVITY DANIELL'S CELL.



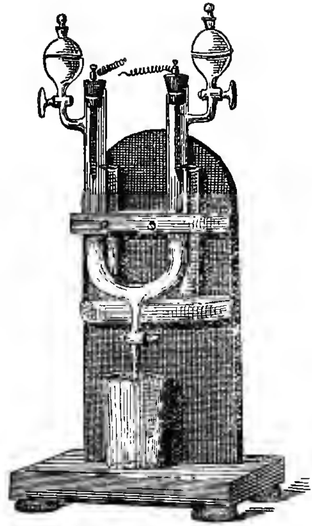
FOR ROUGH LABORATORY WORK IN THE TESTING ROOM.



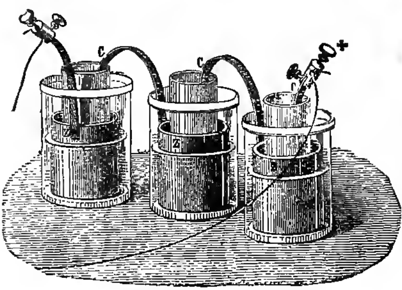
MINOTTO OF HIGH RESISTANCE WITH PAPER PULP OR SAWDUST PARTITION.



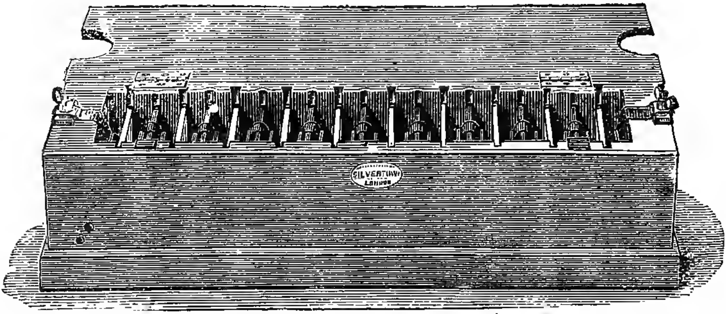
Low Resistance Form.



Dr. Fleming's Standard Cell for Constant Electro-Motive Force of 1·072 Legal Volts.



← Ordinary Lecture-Table Form. Three Cells in Series.



Muirhead's Ten-Cell Telegraph Form.

When the circuit is closed, as shown by the figure (p. 163), the zinc combines with the (SO_4) of the sulphuric acid forming sulphate of zinc ($ZnSO_4$), and thus sets free the two atoms of hydrogen (H_2). This hydrogen passes through the porous partition, but instead of gathering upon the sides of the copper plate and then rising to the surface, it meets with the sulphate of copper ($CuSO_4$), and having a greater natural affinity for the (SO_4) than the copper (Cu) possesses, it displaces the latter and forms sulphuric acid (H_2SO_4), setting *free* pure copper, which is deposited upon the copper plate. This continuous abstraction of *copper* from the sulphate of copper solution would soon weaken the solution if it were not that the copper crystals dissolve, and thus automatically keep the solution saturated with copper sulphate. The chemical composition and action are clearly shown by the two figures (p. 163), so that they need not be further repeated here. This cell, when kept clean and in good order, is fairly constant, *i.e.*, it has a tolerably uniform electro-motive force of about one volt. Of course, if the *internal resistance* of the cell is great, owing to using a dense porous partition, by the plates being far removed from each other, by adopting too small copper and zinc plates, or by failing to keep up the required supply of copper crystals for the proper maintenance of the cell, and thus permitting polarisation to set in, then the *potential difference* obtainable between the + and – terminals or poles of the cell will be diminished.*

The three first figures in the full-page set of different forms of Daniell cells are what have been naturally termed "Gravity

* **Finding the Fall of Potential through a Cell and its Internal Resistance.**—The teacher should perform the following simple experiment before his class, or the students, if there is a laboratory, should each do so for himself, in order to thoroughly realise the above-mentioned causes of the falling off of the potential difference in a cell or battery.

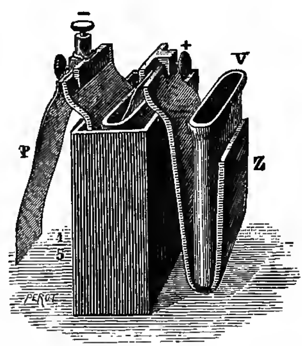
1. Take a Daniell cell in fair condition. Join it up as shown by the last figure (p. 163) with a galvanometer, but let this instrument be either a *very high resistance* voltmeter or a high-resistance Thomson's galvanometer (see Lecture XII.). The cell is therefore practically on open circuit, since a very, very small current flows through it and the voltmeter. The deflection gives you the *Electro-motive Force* of the cell. Let this be $E_1 = 1$ volt.

2. Now join an ammeter or galvanometer of low resistance in circuit between the terminals of the battery, and if need be, include some resistance wire until you have observed any desired current strength flowing from the cell. Let this be $C = \cdot 1$ ampere. At the same time take another reading of your voltmeter. Let this be $E_2 = \cdot 5$ volt, or a falling off of 50 per cent. between the electro-motive force (E.M.F.) previously measured, when giving scarcely any current, and the potential difference between the terminals when the cell is working and giving $\cdot 1$ ampere.

Since E_1 is the E.M.F. and E_2 the P.D. acting *only* on the outside circuit, $(E_1 - E_2)$ must be the *fall of potential* through the cell. Now Ohm's Law, as

Cells," because the sulphate of copper solution, having a higher specific gravity than the sulphuric acid or sulphate of zinc, remains at the bottom of the cell with the copper plate. In the second figure the zinc is merely covered with cartridge-paper, as in Sir William Thomson's large tray cells used for keeping up the magnetism in the electro-magnets, and for driving the mouse-mill, of his telegraph siphon recorder. When it is desirable to have a battery idle for long periods of time, and only to use it now and again, and when a constant E.M.F. is required, then the Minotto high-resistance form with paper pulp partition is preferred. This cell has often a resistance of from 10 to 20 ohms.

Platinum-Zinc or Grove's Cell.—The following illustration is a general view of Sir William Grove's cell and the next figure an enlarged vertical section of the same. The zinc plate, Zn, is cast in the form of a U, and requires to be thoroughly amalgamated. It is generally placed in an ebonite vessel, EV, of ▭ section, and surrounded by sulphuric acid, H_2SO_4 (5 or 6 water to 1 of acid). Inside the U is placed a porous pot, PP, or V for vessel, to match the shape of the outer vessel. Within the porous pot is hung a thin broad sheet of platinum foil, Pt, immersed in fuming nitric acid. Zinc being electro-positive to platinum, the zinc plate is gradually burnt away, forming sulphate of zinc (as we saw before in the case of the Daniell cell), setting free hydrogen, which passes through the porous pot, when it is at once laid hold of by the strong oxidising agent, nitric acid, forming water, H_2O, and red fumes of nitric peroxide gas, NO_2. This gas does not adhere to the platinum foil, neither



OUTSIDE VIEW OF A GROVE'S CELL, SHOWING PLATINUM AND ZINC PLATES AS WELL AS POROUS POT OF NEXT CELL IN SERIES.

pointed out in the last Lecture, states that the *resistance* of *any part* of a circuit is equal to the *potential difference* between the ends of that part divided by the *current* or $\left(R=\frac{E}{C}\right)$. Therefore

$$\text{The Internal Resistance of the Cell} = \frac{E_1-E_2}{C} = \frac{1 \text{ volt} - \cdot 5 \text{ volt}}{\cdot 1 \text{ ampere}} = \frac{\cdot 5}{\cdot 1} = 5 \text{ ohms.}$$

You may vary (1) nature and thickness of partition, (2) the distance between the plates, (3) the size of the plates as immersed, (4) the strength of the copper solution, and (5) the current, taking tests each time and working out the results, so as to bring home to the student the inevitable effect in each case of lowering the potential difference obtainable from a cell.

does it set up any back electro-motive force with the zinc (as the hydrogen does in the case of the simple voltaic cell), so that neither the resistance nor the E.M.F. of the cell appears to be changed by the giving off of this gas; but it is necessary to have the place well ventilated, so as to carry off the fumes quickly, for they are detrimental to the health of the operator and produce a severe headache.

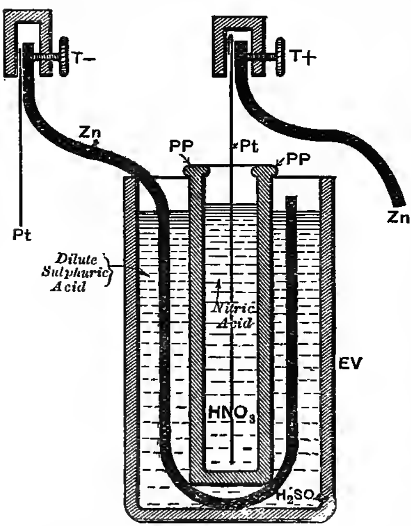
The chemical action on the zinc side of the porous partition is expressed as follows:—

$$\begin{array}{ccccccc} Zn & + & H_2SO_4 & = & ZnSO_4 & + & H_2 \\ \textit{Zinc} & + & \textit{Sulphuric Acid} & = & \textit{Zinc Sulphate} & + & \textit{Hydrogen}\ \text{(passes on)} \end{array}$$

On the platinum side of the porous pot the chemical action is supposed to be—*

$$\begin{array}{ccccccc} H_2 & + & 2\,HNO_3 & = & 2\,H_2O & + & 2\,NO_2 \\ \textit{Hydrogen} & + & 2\,(\textit{Nitric Acid}) & = & 2\,(\textit{Water}) & + & 2\,(\textit{Nitric Peroxide Gas})\ \text{set free} \end{array}$$

Before the introduction of the dynamo-machine and the storage battery or accumulator, this cell and the Bunsen modification of it (see next heading) were the popular cells for producing strong currents when exhibiting the arc light, the heating of wires, the working of a large induction machine, or in fact any effect where a powerful current was required for a few hours' duration. Their strength depends upon the naturally high E.M F., about 1·93 volts in each case, and low internal resistance, from ·01 to 1 ohm, according to size and arrangement. Hence the fall of potential through such a cell or its loss of potential is small. For, adopting the above figures, and assuming that a current of 10 amperes flowed from it, the fall of potential in volts, V, *inside the cell* by

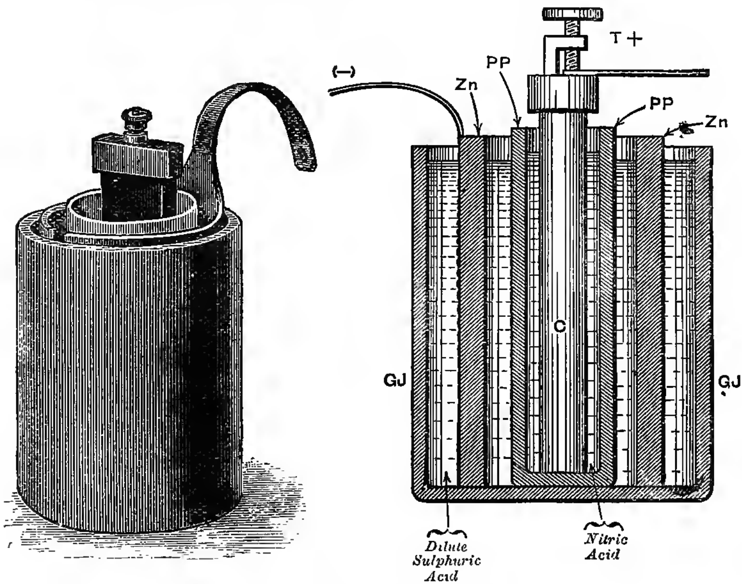


VERTICAL SECTION THROUGH A GROVE CELL.

* At least this is the simplest way of putting the action before the junior student, and there seems to be a doubt about the more complicated formula sometimes stated in text-books.

Ohm's law is only V = C × R = 10 amperes × ·01 ohm = ·1 volt. Therefore, since the electro-motive force is 1·93 volts, the effective potential difference (P.D.) = 1·93 − ·1 = 1·83 volts. Or fifty such large cells in *first-class* condition would supply a 10-ampere current at (50 × 1·83) = 91·5 volts. But if 100 amperes were taken from them, the fall of potential through each cell would be ten times the above, for V = C × R = 100 × ·01 = 1 volt or (1·93 − 1) = ·93 volt left. Even assuming that their internal resistance did not alter, which it very likely would through excessive quantity of gas, we would then have only an effective potential difference of (50 × ·93) = 46·5 volts.

Carbon-Zinc or Bunsen's Cell.—This cell is a simple modification of the Grove cell. Instead of the electro-negative plate platinum, prepared or gas retort carbon, C, is used. It is generally made of larger size than the Grove cell, and of the form



OUTSIDE VIEW AND VERTICAL SECTION OF A CARBON-ZINC BUNSEN CELL.

shown by the accompanying figures. The chemical action and the several index letters to the elements of the battery are the same as in the previous case, with the exception of the outer containing vessel, which is usually a glass jar, GJ, of glazed

earthenware. It would not do to use a copper plate in the nitric acid chamber, as it would soon get burnt away or oxidised, but neither platinum nor carbon suffers in this respect, for they remain perfectly neutral to the acid. The only troubles with such a cell are the difficulty of making good electrical contact with the carbon, the dangers arising from using such strong acid, and the injurious fumes; hence it is not advisable to let junior students use them for experimental purposes. In fact, now-a-days they are seldom used at all where the handy storage cell or secondary battery can be obtained, from which you can get two volts potential difference with a far stronger current and greater constancy for a longer time than from any ordinary Bunsen cell. We shall have occasion to describe the latest form of storage cell in our Advanced Text-Book.*

* For the information of those who may desire to know something now of this interesting and comparatively new invention, we would refer them to Sir David Salomons' book on the use of storage batteries (Part I., 5th edition) and Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables," 8th edition.

LECTURE XVIII.—QUESTIONS.

1. A piece of copper and a piece of zinc are put side by side into a vessel of dilute sulphuric acid. What takes place *in the vessel* when the copper and zinc are joined by a metal wire? What new properties does the wire gain different from what it had before? (S. and A. Exam., 1884.)

2. A strip of platinum and a strip of zinc dip into a vessel of acidulated water. How would you show that two copper wires, fastened one to the zinc and the other to the platinum, are in different electrical states? (S. and A. Exam., 1890.)

3. A piece of zinc and a piece of copper are each carefully weighed. They are then connected by a copper wire and dipped side by side into dilute sulphuric acid contained in an earthenware jar. After, say, half-an-hour, the pieces of zinc and copper are taken out of the acid, washed and dried, and weighed again. Would the weights be the same as at first? If not, how and why would they differ? (S. and A. Exam., 1885.)

4. What is the difference between a single and a double fluid cell? Give examples, with sketches, of each kind.

5. How can local action and polarisation be prevented in a voltaic cell? From what causes do they arise, and what are their effects upon the cell?

6. What are the materials used in the construction of a Daniell's cell, and what chemical changes occur in the cell when in action? (S. and A. Exam., 1888.) Give a sectional sketch of the cell, marking the + and − plates and poles or terminals, and the direction of the current when the circuit is closed.

7. How would the action of a Daniell's cell be modified if the solution of copper sulphate in the porous vessel were replaced by dilute sulphuric acid? (S. and A. Exam., 1890.)

8. A vertical partition of porous earthenware is fitted into a tumbler, and dilute sulphuric acid is poured into each compartment. Rods of common zinc and copper are placed respectively in the two compartments and connected by a wire. State what will be observed with regard to the evolution of gas, and how the observed phenomena will be modified when copper sulphate solution is poured into the compartment containing the copper rod. (S. and A. Exam., 1891.)

9. Describe the Grove's and Bunsen's forms of the voltaic cell, stating what changes go on in them while the current is passing. What is their E.M.F., and how would you calculate the fall of potential through them?

10. If a charged battery is to be kept for some time ready for use, why is it important to take care that the ends of the battery are not connected together outside the battery? (S. and A. Exam., 1886.)

11. The platinum and copper plates of a Grove's and a Daniell's cell are connected by a wire. Would there be a current if the zinc plates were also connected? and if so, in which direction would it flow? What reason have you for your answer? (S. and A. Exam., 1887.)

12. Describe some experiment to prove that when the terminals of a voltaic battery are connected by a wire the battery itself is traversed by an electric current. (S. and A. Exam., 1880.)

13. A number of galvanic cells are connected together in a row so as to form a battery. This row is laid on a table so as to lie north and south. The (−) or zinc is to the north. The poles of the battery are connected together by a wire, which passes from one pole, up one wall of the room, across the ceiling, and down the opposite wall to the other pole of the battery. How will a magnetic needle be affected which is placed under the table and just below the battery? (S. and A. Exam., 1886.)

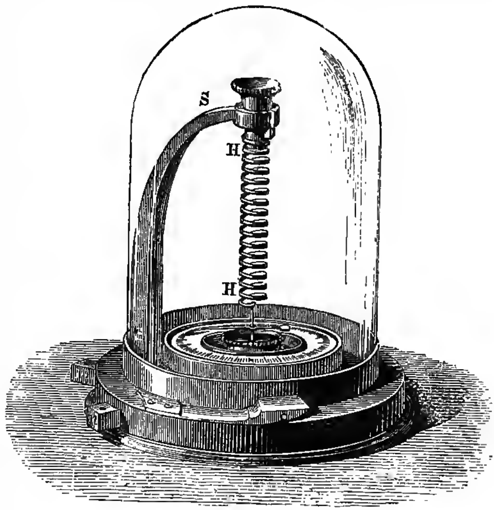
LECTURE XIX.

CONTENTS.—Heat is Developed when a Force Overcomes a Resistance—Table of Good Conductors, Partial Conductors, and Non-Conductors—Illustrations of the Conversion of Electric Energy into Heat—Heat is Developed by a Current in every Part of its Circuit—Heat Developed by a Current in any Part of a Circuit is Proportional to the Resistance of that Part, and to the Square of the Current—The Resistance of a Conductor is Inversely Proportional to the Area of its Cross Section—Questions.

IN Lectures IX. to XVII. we entered very fully into the magnetic and mechanical effects of the electric current, and we made one allusion to a physiological effect in the case of Galvani's and Volta's experiments upon the contraction of frog's muscles. We shall now discuss in this Lecture the heating, and in the next one the chemical effects, of currents.

Heat is Developed when a Force Overcomes a Resistance.—Whenever a body is set in motion by a force, part (or, in certain cases, it may be the whole) of the mechanical energy is expended in overcoming frictional resistance. This portion of the force or *Mechanical Energy* is directly transformed into *Heat Energy* in the act of overcoming the mechanical or frictional resistance. *For example*:—A person slips down a vertical rope by holding it between his hands and his legs. The force of gravity impels him downwards, overcoming the frictional resistance between his hands and limbs and the rope, with the consequence that they become severely heated, more especially if he happens to slip down quickly. A boy takes a run, and then slides along a level piece of ice: the mechanical energy stored up in him just before he begins to slide is expended partly in overcoming the frictional resistance between the soles of his boots and the ice, and partly in the frictional resistance between his clothes and the air. As a consequence, he will find that by the time he gets to the end of the slide his soles are considerably warmed. If the ice were perfectly level, infinitely long, and absolutely devoid of friction (between it and his boots), and if there was no frictional resistance between him and the air, then he would slide on *for ever!* If we could diminish the frictional resistance between the skin of a ship and the water and air through which it passes, to nothing, then all that would be required to transport her across the Atlantic would be a strong force applied

at the start until she attained the desired speed, when she would proceed forward, and arrive at her destination with undiminished velocity! In reality, however, we find it necessary to employ steam-engines of 10,000 horse-power continuously in order to propel an Atlantic "greyhound" of 5000 tons at twenty knots an hour in the calmest of weather. About one-half of this power is absorbed in overcoming the frictional resistance of the ship through the water, and the other half in the frictional and other losses due to the working of the internal machinery. Examples of the conversion of mechanical energy into heat energy are so familiar to you all, being in fact brought prominently before your notice every day of your existence, that we need not further enlarge upon this side of the question. What we now wish more particularly to impress upon you is this, that whenever and by whatever means an electro-motive force is set up in any electrical circuit, a current is started in that circuit, and if it were not for the *ever-present* electrical resistance which it has to overcome, the current would flow on for ever! The part of the *Electrical Energy* which is expended in overcoming the conductor's resistance is directly transformed into *Heat Energy*. All substances offer resistance to the passage of an electric current. Some, such as the metals, offer a comparatively small resistance, and are therefore termed "*good conductors;*" others, such as pure water and the human body, &c., offer a considerable resistance, and are termed "*semi-conductors;*" whilst silk, sealing-wax, gutta-percha, india-rubber, glass, and dry air, offer an enormous resistance, and are termed insulators or "*non-conductors.*" No substance, however, offers such a high resistance that it can-



BREGUET'S CURRENT THERMOMETER.

not be traversed by a current when sufficiently great electromotive force is applied. For in the case of *Lightning*, we have flashes of electricity forcing their way through miles of dry air, and thus generating in their paths a considerable quantity of heat, accompanied by light, the natural outcome of a high temperature.

THE FOLLOWING TABLE SHOWS THE ORDER IN WHICH THE VARIOUS SUBSTANCES MENTIONED OFFER ELECTRICAL RESISTANCE TO THE PASSAGE OF A CURRENT:—

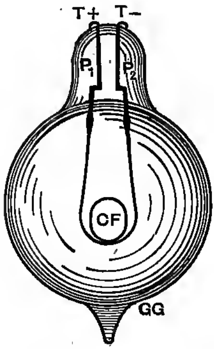
Good Conductors.	*Fair Conductors.*	*Semi-Conductors.*	*Non-Conductors or Insulators.*
Silver (*best*).	Charcoal.	Water.	Paper (dry).
Copper.	Coke.	The body.	Oils.
Gold.	Carbon.	Flame.	Porcelain.
Aluminium.	Acids.	Linen.	Silk.
Zinc.	Saline solution.	Twine.	Sealing-wax.
Platinum.	Sea-water.	Cotton.	Sulphur.
Iron.	Earth.	Dry wood.	Resin.
Nickel.		Marble.	Gutta-percha.
Tin.		Slate.	India-rubber.
Lead.			Shellac.
German silver.			Paraffin wax.
Platinum silver.			Ebonite.
Antimony			Glass, dry and warm (varies much with the quality).
Mercury.			Dry air.
Bismuth			

Illustrations of the Conversion of Electric Energy into Heat.

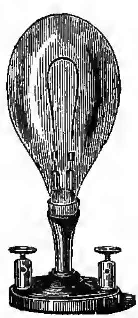
EXPERIMENTS XXXI.—(1.) In order to illustrate the conversion of the energy of an electric current into heat energy, take a simple spiral or helix of steel, German silver, platinum, or platinoid wire, H, and suspend it from a support, S, with the lower end dipping into a mercury cup, as shown by the accompanying figure. Fix a pointer to the lower end of the wire, with a graduated scale underneath, and connect your battery terminals to the terminals of the instrument marked *m* and *n*. The passage of the current through the wire in overcoming the electrical resistance of the wire heats the same, causing it to expand, and to slightly unwind the spiral, thus turning the pointer over more or less of the scale, according as the current, and hence the temperature developed, is great or small.

(2.) Take an open spiral of steel or platinum or German silver wire, and suspend it inside a vessel containing water or any liquid. Connect the ends of the wire to a battery capable of giving a strong current, and in a very short time you will find that the water begins to boil.

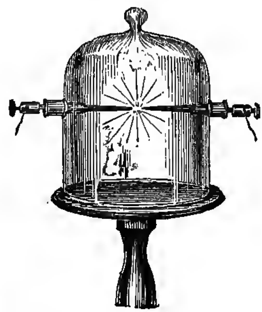
(3.) Take an ordinary incandescent lamp supported by a portable stand, as shown by the second figure below, or a Swan's glow-lamp, as shown by the first figure, where CF represents the carbon filament, and P_1, P_2, the platinum leading-in wires, attached to the ends of CF by carbon paste. The platinum wires are hermetically sealed into the glass globe, GG, at the places where they pass through it, and the air is extracted as far as



SWAN'S GLOW LAMP.



INCANDESCENT LAMP WITH PLATINUM OR CARBON FILAMENT.



ARC LIGHT IN VACUUM.

possible from the interior of the globe by a vacuum pump. Attach the poles of a battery or working dynamo to the lamp terminals T+ and T−, and thereby cause a current to pass through the carbon filament until it glows with a pure and beautifully white brilliance. Hold your hand upon the outside of the globe; you feel it hot, but not so hot as you would have expected from the very intense white heat that exists in the filament. The intensity of the heat in the filament is great, being represented by a temperature of about 1900° Centigrade, but the quantity of the heat developed is small.* The heat

* The heat generated by a current of C amperes passing through a conductor of R ohms for T seconds is represented by the formula $C^2 \times R \times T \times \cdot 24$ Therms (where a therm is the amount of heat required to raise 1 gramme mass of water from 4° to 5° Centigrade). Consequently, in the case of an ordinary 16-candle Swan lamp of 65 ohms resistance hot, requiring 1 ampere of current, we have for every second of time that the lamp is worked only about $15\frac{1}{2}$ therms of heat developed in the filament.

For, $C^2 \times R \times T \times \cdot 24 = 1^2 \times 65 \times 1 \times \cdot 24 = 15 \cdot 6$ therms.

See Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables" pp. 15, 16, 385.

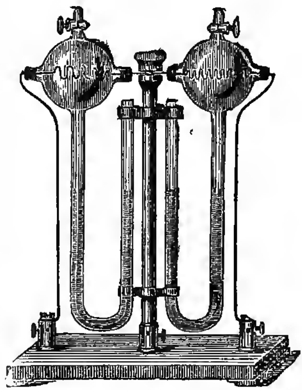
energy developed by the current's energy in overcoming the resistance of the carbon filament is in this case further transformed into light radiations, owing to the intensity of the heat or extremely rapid vibrations imparted to the molecules of the carbon by the current. We obtain this light with little or no consumption of carbon, since the filament is enclosed in such a perfect vacuum that practically no combustion of the carbon takes place.

(4.) Instead of a continuous carbon rod or filament, you may adopt the method illustrated by the third figure, where two carbon pencils are held fairly opposite each other by adjustable terminals passing through air-tight stuffing-boxes. On joining these terminals to the battery or dynamo, and bringing the carbon points into contact, and then separating them by a very short distance, an "arc is struck" between them, producing a most intense heat of about 3000° Centigrade, and a very brilliant white light. This light may be maintained in a vacuum, as you can readily prove by exhausting the air from the bell-jar containing the carbon. The now well-known arc light, which you see at all the important railway stations, and in many of the large workshops, consists simply of two such carbon rods, kept apart at the required distance by mechanism automatically controlled by the current which overcomes the resistance and back, E.M.F., of the arc.

Heat is Developed by a Current in every Part of its Circuit. —EXPERIMENT XXXII.—We have seen by the last set of experiments that heat is developed in the outside circuit. We shall now prove to you that it is developed not only outside the battery or generator, but also inside the same, and, in fact, in every part of the circuit, proportionally to the resistance overcome by the current. Take two or three Grove, or Bunsen, or Daniell cells with large plates, and consequently low internal resistance, and join them up in series with a few feet of steel or platinum wire.* The wire gets hot, and so does the liquid inside the cells, as you may easily prove by inserting a thermometer inside and outside of the porous division. If you employed a dynamo instead of a battery, you would have found that the armature and field-magnets, indeed, every part of the generator, became warm if you caused it to give forth a current proportionately strong to the size of the wires of which these parts are composed.

* It is also advantageous to join into the circuit a low-resistance current meter, so that you may know exactly the current strength which you employ in each case.

Heat Developed by a Current in any Part of a Circuit is Proportional to the Resistance of that Part and to the Square of the Current.—EXPERIMENT XXXIII.—Take a simple piece of apparatus illustrated by the accompanying diagram, where you have a platinum wire of a certain length inserted into the left-hand bulb, and say exactly double that length of the same size of platinum wire inserted in the right-hand bulb, which is exactly the same size as the other globe. Fill the U tubes partially with water, as shown by the shading, and then pass the same current through the two platinum wires joined in series as shown. You find that the water in the graduated open side of the *right*-hand U tube rises to about double the height above the normal position that it does in the graduated open side of the *left*-hand U tube. Now, *a gas under constant pressure expands by a definite fraction of its volume for a given increase of temperature*, consequently the air in the right-hand bulb must have been raised to double the temperature of that in the left-hand one, or double the quantity of heat has been developed in the wire of double length by the current. Again, it can be easily proved by another experiment, but common reasoning would lead you to the conclusion that the *resistance* of any uniform section of homogeneous conducting substance (such as a wire of uniform material and uniform diameter) varies directly as its length. Consequently, double the length of the wire under test has double the resistance. *Hence the heat generated is proportional to the resistance.* This leads you naturally to the conclusion that if you double the distance between the plates in any cell, you double the resistance of that cell, and if the same current be taken from it under each of these conditions, twice the heat will be evolved in the cell when its plates are twice as far apart.



FOSTER'S LECTURE EXPERIMENT.

To prove that the heat developed is proportional to the square of the current it it is necessary to put a current meter in circuit with Foster's apparatus. Suppose you *double* the current passing through the two platinum wires; then you will find that the liquid rises to about *four* times its former rise in each of the open-ended graduated tubes. Increase the strength of the current to *three* times its original amount, and the water rises

to about *nine* times its original rise. Consequently, *the heat developed in a conductor is directly proportional to the square of the current passing through the conductor.* The proper proportioning of the size of conductors to carry currents for electric lighting and transmission of power is one of the most important points that the electrical engineer has to deal with. The problems which arise in connection with a full investigation of this subject are both interesting and complicated.

The Resistance of a Conductor is Inversely Proportional to its Cross Section.—The student is not sufficiently advanced to understand the construction and action of the apparatus usually employed for demonstrating with accuracy this fact, but he has only to be shown the simple experiment of joining in series, with a battery or dynamo, two wires of the same material and of the same length, but one, say, double the cross area of the other, when he will see that the thinner wire becomes much hotter than the thick one, and he can be led to reason therefrom that the former has the greater resistance. In the same way he may be shown that if the size of the battery plates is doubled, the current derivable therefrom (with constant resistance in the outside circuit) is increased; in fact, that the internal resistance of the cells has been diminished by half. And as a natural consequence, arising from the reduction of the internal resistance of a cell or battery by bringing the plates closer together or by increasing their size, the student may be shown that the outside connecting wire becomes hotter, due to an increase in the current. For, by Ohm's Law, $C = \frac{E}{R}$, and if E, the electro-motive force of the battery, remains constant, whilst R (which represents the combined resistance of the battery and wire) is diminished, then C, the current, must increase proportionately to the *decrease* of R. Or, by the knowledge derived from pp. 90, 91, and 156, this law may be proved by the following experiment. Take two equal lengths (A and B) of the same kind of wire, but let B have twice the cross sectional area of A. Wind the whole of A and half the length of B side by side on a detector galvanometer bobbin. First, connect the adjacent free ends of these two wires firmly together, and then join the two ends to the poles of a battery. No deflection of the galvanometer needle will be observed. Since only half the number of turns of the B wire are on the bobbin that there are of the A wire, B must be carrying double the current of A; and since the same potential difference acts on both wires, B must, by Ohm's Law, have only half the resistance of A. But B is twice the cross section of A, *therefore resistance varies inversely as the cross section.* B might be taken as n times the cross section of A, and then only $\frac{1}{n}$ of B wound on the bobbin, when, if the battery was applied as before, no deflection would be observed on the needle, thus proving the law to be generally true. By altering the length of B in circuit exterior to the coil, a deflection is at once observable, showing a want of balance. The student will thus see that it is only with the above arrangement that equilibrium is possible.

Lecture XIX.—Questions.

1. When mechanical and electrical forces overcome resistance, into what form of energy are they transformed? Give two practical examples to illustrate your answer.

2. How would you prove that when an electric current passes through a circuit heat is developed in every part of that circuit?

3. A delicate thermometer is immersed in dilute acid into which plates of zinc and copper are dipped. When the plates are connected by a copper wire, the temperature of the liquid rises. Why is this? (S. and A. Exam., 1889.)

4. How is it that if the poles of a battery are connected by a long thin wire, the battery does not get so hot as when a short thick wire is used? (S. and A. Exam., 1883.)

5. A current flows through a copper wire, which is thicker at one end than at the other. If there is any difference either (1) in the strength of the current at, or (2) in the temperature of, the two ends of the wire, state how they differ from each other, and why. (S. and A. Exam., 1888.)

6. If a plate of copper and a plate of zinc connected by a wire are dipped into dilute sulphuric acid, the connecting wire gets hotter when the plates are brought nearer together, and cooler if they are separated to a greater distance. Why is this? (S. and A. Exam., 1885.)

7. What alteration is made in the current from a cell (*a*) by increasing the size of the plates; (*b*) by bringing them nearer together; (*c*) by shortening the wire connecting their + and − poles. (S. and A. Exam., 1879.)

8. How could you boil water by means of the current from a voltaic battery? Give a sketch of the apparatus you would use. (S. and A. Exam., 1886.)

9. Two Grove's cells, alike in all respects except that in one the plates are twice as far apart as in the other, are arranged in series, and the poles of the battery so constituted are united by a copper wire. The liquid in both cells becomes heated. In which is the rise in temperature the greater, and why? (S. and A. Exam., 1889.)

10. A number of cells formed of plates of zinc and platinum, immersed in dilute sulphuric acid, are to be connected in a circuit, so that the platinum of each cell is in contact with the zinc of the next. What effect, if any, would be produced on the current if, by mistake, one cell was made up with two platinums, instead of with one platinum and one zinc plate. (S. and A. Exam., 1889.)

11. One pole of a strong bar magnet is put through a copper ring and quickly taken out again. This is done repeatedly and quickly. Although the magnet and ring are not allowed to rub against each other, the ring becomes slightly heated; why is this? (S. and A. Exam., 1881.)

12. A circuit includes an insulated battery and a galvanometer. Will the indication of the galvanometer be affected if a point in the circuit (*e.g.*, the negative pole of the battery) is directly connected with the earth? Give reasons for your answer. (S. and A. Exam., 1891.)

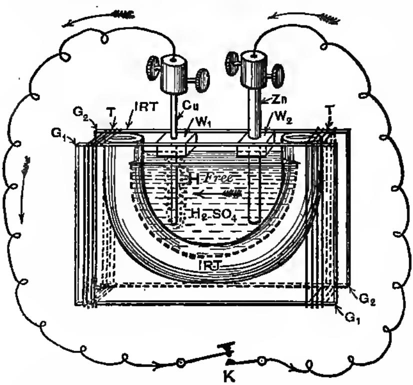
13. The poles of a battery are connected by a long wire. Of this, two lengths of 6 inches, one near the positive pole, the other half-way between the poles, are immersed in two similar vessels of water. Will there be any difference in the amounts of heat produced in the two? Give reasons. (S. and A. Exam., 1891.)

LECTURE XX.

CONTENTS.—Polarisation Inside a Single Fluid Cell, Illustrated by the Magic-Lantern—Electro-Chemistry, or the Decomposition of Liquids by Electric Currents—Definition of Electrolysis, Electrolyte, Electrodes, Anode, Cathode, Ions, Cathion, Anion, Migration of Ions, Velocity of Ions, Voltameter—Electrolysis of Water—Electroplating—Electrotyping—Determining the Direction of a Current in a Circuit and the Poles of a Battery or Dynamo by Electrolysis—Questions.

IN Lecture XVIII. we explained, by aid of diagrams and chemical notation, the decomposition which takes place *inside* several different kinds of battery cells whenever the circuit was completed. We shall now describe, by aid of the magic-lantern, how Polarisation takes place, and acts, in the case of a single fluid cell, as this will pave the way to your understanding the decomposition of water and other electrically decomposable liquids.

Polarisation Inside a Single Fluid Cell, Illustrated by the Magic-Lantern. — EXPERIMENT XXXIV. — *First*, Construct a simple cell like that shown in the accompanying figure, by taking two ⊔-shaped pieces of thin, clear window-glass, G_1, G_2. Insert a piece of ordinary india-rubber tubing, IRT, between G_1 and G_2, and bind the whole firmly together at each end by twine, T, T. Pour into this water-tight cell some dilute sulphuric acid, H_2SO_4, and then fix the cell into the magic-lantern between its condensing and focussing lenses. Focus the light upon a white screen until you obtain a clear and well-defined image of the cell.



SIMPLE SINGLE FLUID CELL FOR ILLUSTRATING POLARISATION BY THE MAGIC LANTERN.

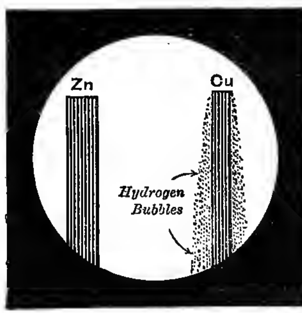
Second, Introduce into the cell a rod or strip of *pure* copper, Cu,

with a fitting strip of wood, W_1, so as to keep the former in a vertical or an inclined position midway between G_1 and G_2. You observe that at this stage no signs of chemical action are given by the figure cast upon the screen.

Third, Introduce into the cell (at some little distance from the copper) a rod or strip of *pure* zinc, Zn, with its fitting strip of wood, W_2, as shown. You still observe no chemical action.

Fourth, Close the circuit by means of leading wires and a key, K, as shown. You immediately see clear indications of chemical action manifested on the image, being represented by numerous bubbles of gas gathering, as well as apparently falling down from the copper plate.* These bubbles, as may be proved by gathering and testing a quantity of them, are composed of pure hydrogen gas.

Fifth, You may neglect completing the circuit *outside* the cell by simply inclining the copper and zinc rods towards each other until they make contact *inside*, when you see the same polarisation effects as in the last case.



MAGIC LANTERN IMAGE OF POLARISATION IN A SINGLE FLUID CELL.

Sixth, You may substitute a strip of platinum foil or a rod of carbon for the copper rod, and upon completing the circuit *outside* or *inside* the cell you obtain polarisation bubbles of hydrogen.

Seventh, You may substitute a piece of *impure* zinc for the *pure* piece, and whether you have copper, platinum, or carbon as the electro-negative plate, also whether the circuit is complete or not, you will observe the effects of local action *at the surface of the impure zinc* by a violent stream of gas bubbles and detached particles of zinc coming off from the zinc rod.

Eighth, You may put in a thin porous division of unglazed paper between the rods, with nitric acid surrounding the carbon, or weak sulphate of copper surrounding the copper, and with sulphuric acid surrounding the zinc, and note the results as shown upon the screen. These experiments are most interesting

* The image cast upon the screen is an inverted view of the cell in the magic-lantern, for it is turned upside down by the lenses. If you introduce a properly focussed pyramidal prism between the focussing lens of the magic-lantern and the screen, you will again reverse the image, and thus depict it as a naturally placed view of the cell. Then the hydrogen bubbles will be seen rising on the screen as they actually rise from the copper plate in the cell.

and instructive, besides having the additional benefit that they may be simultaneously viewed by a large class.

Electro-Chemistry, or the Decomposition of Liquids by Electric Currents.—Chemical action not only takes place *inside* every form of chemical battery, but the current in the *outside* circuit is also capable of producing chemical decompositions when it is passed through *certain liquids.* This action comes under the general heading of electro-chemistry, and it has been put to practical use in a large variety of cases, such as the production of gases, the electroplating of spoons, forks, and other household appliances, and the electrotyping of diagrams, such as those used in the illustration of this book, together with the production of pure copper and other metals upon a large and marketable scale, which is notably the case in the manufacture of copper steam-pipes for high-pressures by the Elmore process. These three last-mentioned practical applications of electro-chemistry are generally included under the particular term "Electro-Metallurgy."

We have just said that *certain liquids* were decomposed by the passage of an electric current. The reasons for this qualification are, that—

(1.) There are liquids, such as mercury and other molten *pure* metals, which conduct electricity without showing any signs of decomposition.

(2.) There are other liquids, such as petroleum, paraffin, and oils, which offer such a high resistance to the passage of electricity that no ordinary electro-motive force will cause a current to flow through them.

(3.) There are those liquids, such as acidulated water, sulphate of copper, and cyanide of silver, which are readily decomposed by an electric current. It is this last group of liquids that are referred to in the above remarks, and with which we have now to deal.

Before explaining the following experiments, it may be as well to state and define Faraday's nomenclature in regard to electrolysis, since it has been universally adopted by physicists and electricians.

DEFINITIONS.*—(1.) *Electrolysis.*—"If an electric current is passed through liquids of a certain kind, consisting either of certain compounds in a state of fusion or dissolved in certain solvents, the bodies present undergo chemical dissolution. The act of undoing chemical combination by the aid of an electric current or electric discharge is called *electrolysis.*"

* These definitions, as we have stated them, were drawn up by Professor Fleming, D.Sc., Convener of the Nomenclature and Notation Committee appointed by the Institution of Electrical Engineers, in response to a paper on "Electrical Definitions, Nomenclature, and Notation," read by the author before the Institution in 1886.

(2.) *Electrolyte.*—"Any compound chemical body which is capable of undergoing a chemical dissolution by an electric current is called an *electrolyte.*"

(3.) *Electrodes.*—"The metallic or conducting plates, wires, or other conductors by which the electric current is led into and conveyed from the electrolyte undergoing electrolysis, are called *electrodes.*"

(4.) *Anode.*—"The electrode by which the current *enters* the electrolyte is called the *anode.*" From the Greek word ἄνα, signifying *upwards*, and ὁδός, *way.*

(5.) *Cathode.*—"The electrode by which the current *leaves* the electrolyte is called the *cathode.*" From the Greek word κατά, signifying *downwards*, and ὁδός, *way.*

(6.) *Ions.*—"The chemical compounds or elements into which the electrolyte is broken up are called the *ions.* The ions appear at the immersed surfaces of the electrodes."

(7.) *Cathion.*—"The ion appearing at the cathode is the *cathion.*" Κατιών, *that which goes down.*

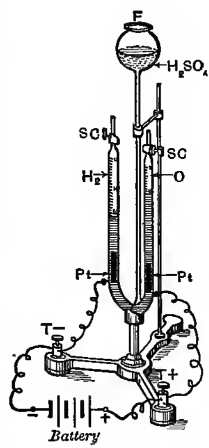
(8.) *Anion.*—"The ion appearing at the anode is the *anion.*" Ανιών, *that which goes up.*

(9.) *Migration of Ions.*—"The movement of the ions through the electrolyte, to appear at the electrodes, is called the *migration of the ions.*"

(10.) *Velocity of the Ions.*—"The ions move through the electrolyte with variable but definite velocities, depending on the nature of the ion, temperature, and density of the liquid or solution. Each ion, under given circumstances, has a specific *ionic velocity.*"

(11.) *Voltameter.*—"Any vessel or apparatus employed for performing and measuring electrolysis is called a *voltameter.*"

Electrolysis of Water. — Experiment XXXV.—Take a graduated Hoffmann's voltameter, as illustrated by the accompanying figure, and pour dilute H_2SO_4, or acidulated water,* down the funnel, F, opening the stopcocks, SC, at the top of each limb of the U tube, until the liquid just runs over at the cocks. Then shut the cocks and pour in more of the liquid until it rises half-way in the funnel, as shown by the figure. Connect *two or three* low-resistance Daniell, Grove, or Bunsen cells to the terminals T + and T −, which are permanently connected to the platinum plates, P*t*, P*t*, inside each limb of the U tube. Immediately bubbles of *oxygen* gas rise in the *right-hand* vertical stem, where the current *enters* (*i.e.*, at the anode), and displace the liquid therein. At the same time bubbles of hydrogen gas are given



Hoffmann's Voltameter.

* *Pure* water offers such a high resistance to the electric current, that it is found difficult to decompose it without the addition of a few drops of sulphuric or of hydrochloric acid, which at once reduces its resistance and facilitates the electrolysis.

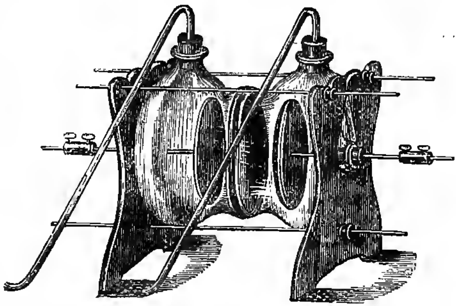
off in the left-hand tube where the current *leaves* (*i.e.*, at the cathode), and thus displace the liquid therein. If you wait a short time, you will find that the volume of hydrogen gas given off is double that of the oxygen liberated in the same time, for the composition of water is two volumes of hydrogen to one of oxygen, or H_2O, as expressed in chemical notation. After gas has been liberated—say, until the point of the left-hand platinum plate appears above the liquid—you may open the stopcock and apply a lighted match to the opening, when the *hydrogen* will burn with its characteristic bluish flame. A simple red-hot match-end applied to the other opened stopcock shows one of the characteristic features of *oxygen*, viz., that it supports combustion by immediately causing the incandescent match to burst into a flame.

There is one important point worthy of notice here, viz., that you cannot electrolyse any substance without experiencing a polarising or contrary electro-motive force to that of the decomposing current. The value of this back E.M.F. seems to be a direct measure of the "chemical affinity" or tendency of the disunited ions to reunite again. For example, the moment you split up water into its constituent elements, hydrogen and oxygen, then these two gases having a "chemical affinity" for each other, tend to reunite, and in doing so, an electro-motive force of about 1·5 volts is set up between them in the *opposite* direction to that of the current which separates them. Consequently, you cannot decompose water with a less electro-motive force than 1·5 volts, for nothing less will overcome the natural chemical affinity holding the elements together. Now a Daniell cell only gives an internal E.M.F. of 1·1 volts at most, but this E.M.F. falls in pressure in overcoming the internal resistance of the cell, so that in all probability not more than 0·9 volt of potential difference is available for external work between the terminals of the Daniell cell. You can now understand why it is that one Daniell cell cannot decompose water, and that it requires two such cells joined in series to separate the elements oxygen and hydrogen. Even if you do employ two such cells of an E.M.F. of 1·1 volt each, with an internal resistance of 2 ohms each, and suppose that the connecting wires and the internal resistance of the voltameter combined, equals 3 ohms, then:—

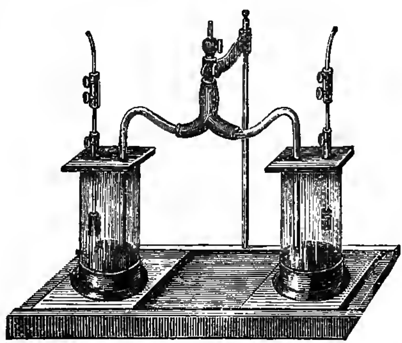
$$\text{By Ohm's Law, } C = \frac{E}{R} = \frac{(2 \cdot 2 - 1 \cdot 5) \text{ volts}}{(2+2+3) \text{ ohms}} = \frac{\cdot 7 \text{ volt}}{7 \text{ ohms}} = \cdot 1 \text{ ampere.}$$

You only get $\frac{1}{10}$th ampere of current through the system. In the same way you can work out the current which you can pass through any electrolytic cell or bath if you know the forward E.M.F. of your battery cell, the back E.M F. of your electrolytic cell, and

the resistances of each part of your circuit. For in every case of electrolysis the E.M.F. of your battery has not only to overcome the internal resistance of the same, but also the external resistance, and in addition the back or contrary E.M.F. of polarisation, before a continuous steady decomposing current can be kept up. In practice it is usual to employ two or three Grove's, or Bunsen's, or storage cells joined in series when decomposing water for the purpose of class demonstration. A transparent cell, similar to that illustrated by the first figure in this Lecture, may be placed in the magic-lantern with two platinum-foil plates, instead of the zinc and copper rods, and the action observed by the image cast upon the white screen. When the current has been kept up for a short time, you may disconnect the leading wires from the battery and connect them up to a sensitive galvanometer, when the polarisation E.M.F. will produce a current through the galvanometer and voltameter in the opposite direction to that of the former decomposing current, *i.e.*, the current will start at the hydrogen electrode, pass through the voltameter to the oxygen electrode, and from thence through the galvanometer outside to the hydrogen electrode.



APPARATUS FOR DECOMPOSING LARGE QUANTITIES OF WATER AND COLLECTING THE GASES SEPARATELY.



WIEDEMAN'S APPARATUS FOR THE ELECTROLYSIS OF SALINE SOLUTIONS.

If you desire to decompose large quantities of water and to collect the gases separately, you should use an apparatus like that illustrated by the above figure. If the oxygen and hydrogen thus liberated be collected in one strong gas-tight

vessel, and an electric spark be passed through them, they will instantly recombine with an explosion and form water. For the electrolysis of saline solutions Wiedeman's apparatus, as shown by the foregoing figure, will be found convenient, because it can be fitted with graduated tubes for accurately measuring the respective volumes of the gases given off.

There is another important point worth mentioning, viz., that the quantity of gas given off per second is a direct measure of the mean strength of the current flowing through the circuit, but into the details of this test as well as the several laws of electrolysis we cannot at present enter, for they are naturally beyond the range of this elementary course.

Electroplating.—The term electroplating signifies the process or art of depositing a coating of one metal on the surface of another metal from a solution containing the former by aid of an electric current. The metal held in solution is always deposited on the negative electrode or cathode. In other words, the metal always "goes down" with the current just as we saw, in the case of the electrolysis of water. Hydrogen goes down with the current and appears at the electrode where the current leaves the voltameter. When gold is deposited upon any baser metal, the process is termed electro-gilding. In the case of electro-gilding, or in the case of electroplating any article with silver, the solutions are always alkaline, and generally a cyanide of the metal to be deposited is used for the solution, along with a plate of gold or of silver as the positive electrode. This plate is dissolved into the solution by the action of the current at about the same rate that the metal is thrown down from the solution, so that the quantity of metal held in solution does not vary much during the operation.

Experiment XXXVI.—Suppose you wish to coat an iron spoon with silver; you would previously require to deposit copper upon it, because silver will not take well directly upon iron.*

First, Thoroughly clean the iron spoon, and hang it from an insulated metal support by a leading wire or clip (connected to the negative pole of your battery) in a vessel containing a solution of sulphate of copper.† (See next figure.)

Second, Hang a pure copper plate in the solution from another insulated metal support opposite the spoon, and connect this

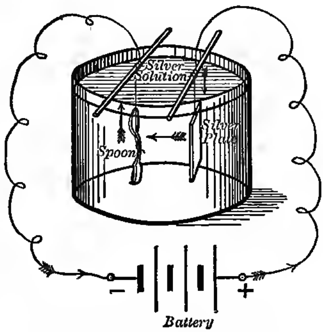
* See Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables," pages 325 to 345, for details of the processes, such as cleaning and rate of electroplating with copper, silver, nickel, gold, &c.

† A saturated solution of sulphate of copper, mixed with one-fourth of its volume of water and with one-tenth of its volume of oil of vitriol or strong sulphuric acid, will do very well.

plate to the positive pole of your battery, which should have two or three volts of free E.M.F. or potential difference between its terminals.

Third, After the spoon has received a thin, hard coating of copper, remove it from the bath, clean it, and burnish it bright, so as to remove all scratches.

Fourth, Put the copper-coated iron spoon into a bath containing a solution of silver * and a pure silver plate, and join them up with your battery, as shown by the accompanying figure.



ELECTROPLATING A SPOON WITH SILVER.

Fifth, After keeping on the current for a longer or a shorter time, according as you desire a thick or a thin coating of silver, take out the spoon from the solution, clean and buff it bright, when you will have a beautiful shining article, to all intents and purposes as pretty as, certainly much stronger and less likely to be stolen than, if it were composed of solid silver.

Not only metals, but also most solid substances may be coated with nickel, silver, gold, &c., by simply covering their surfaces with powdered plumbago or blacklead, and then putting them into the electroplating copper bath, and finally into the silver, nickel, or gold one, as just explained. Natural objects, such as flowers, leaves, ferns, insects, &c., give pretty effects when coated or coloured with different metals. These things cannot be blackleaded or coated mechanically, but they may be prepared by dipping them into a solution which can either penetrate them or form a perfect film of some material, which will then receive a thin skin of silver or gold.†

Electrotyping.—The term electrotyping is applied to the process or art of reproducing (usually in copper) facsimiles of coins, printed type, woodcuts, or any impressionable form of an object by aid of electric currents. Most of the figures in this book are printed from copper electros, or cliches, as they are sometimes called. The process is as follows.

* The silver solution, if it is made up of two parts cyanide of silver dissolved in ten parts of cyanide of potassium, and then filled up with pure water, so as to give about two ounces of silver to the gallon of liquid, will do very well.

† See page 338 of Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables" for methods of treatment, &c., in such cases.

Experiment XXXVII.—*First*, Clean the coin, type, or woodcut, since even a dirty finger-mark is faithfully reproduced by the electrotype.

Second, Take a firm impression on bees-wax, gutta-percha, or plaster-of-paris of the article, and coat the surface of the impression with a fine covering of blacklead carefully brushed over with a camel-hair brush, so as to form a uniform conducting surface, at the same time taking great care not to obliterate any of the finer marks or impressions.

Third, Hang up this impression as a negative electrode or cathode in a solution of sulphate of copper.*

Fourth, Hang a pure copper plate in the solution as an anode, and pass a current through the circuit (just in the same way as you saw done in the case of coating the iron spoon with copper), until you obtain the desired thickness of copper deposit.

Fifth, Take the cathode from the electrolytic bath or cell, and gently remove the copper deposit from its wax or plaster bed.

Sixth, In the case of electros or electrotypes for books, where great pressure has to be subsequently brought to bear upon them in the process of printing, the back of the thin copper electro is covered with solder, and a backing of melted white metal is then poured upon it to the thickness of $\frac{1}{10}$th of an inch or more, when it soon cools and firmly adheres to the sweated surface of the thin electro. The back surface of this white metal backing is then planed perfectly flat and the whole screwed to a block of hard wood, usually of mahogany. In this way, electrotypes are prepared which will permit of 100,000 or more impressions being taken from them; whereas, soft metal casts or cast stereotype plates will not stand more than 10,000 impressions or printings without showing signs of fagging. Whenever a book is expected to demand 100,000 or more copies, not only the figures but the whole of the type are electrotyped before a single public copy of the book is printed off; and if the figures require to be very finely brought out, the copper deposit is made extra thick and hard. The rate at which the copper is deposited determines the hardness of the electro. The less the density of current employed (*i.e.*, the amperes per square inch of cathode), the harder will be the copper deposited upon it.

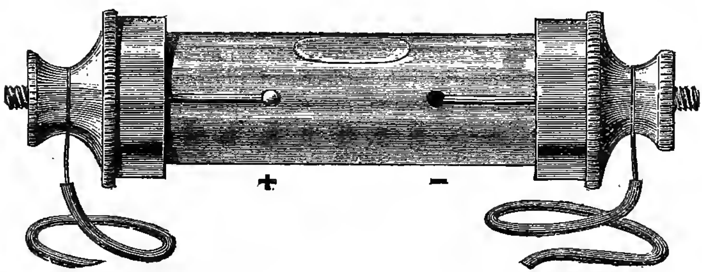
Determining the Direction of a Current in a Circuit and the Poles of a Battery or Dynamo by Electrolysis.—You were made perfectly familiar with the method of determining the direction of the current in a circuit as well as the poles of a hidden battery or dynamo by aid of the movements of a compass-needle held near

* See footnote to page 186.

the wire through which a current flowed in the Lectures on Electro-Magnetism. We shall now show you that the same object may be attained by observing the effects produced in a water voltameter or electrolytic cell.

Experiment XXXVIII.—*First*, If you connect up the wires leading from any generator of electric currents which is capable of decomposing water to the electrodes of a water voltameter (as illustrated by the figures under the section "Decomposition of Water"), you have only to wait a few minutes until you observe at which electrode the greater quantity of gas is being given off, in order to make sure that that must be the side where hydrogen is being generated, or, in other words, where the current is leaving the voltameter. Consequently, *the pole of the generator connected to this negative electrode must be the* **Negative** *pole.*

Second, If you dissolve a few crystals of iodide of potassium in water, adding a little starch thereto, and then pass a current through the solution, iodine is liberated at the anode, producing a blue colour by its action on the starch where the current enters. In this way you can at once tell the wire which is connected with the **Positive** pole of the generator. Acting upon this principle,

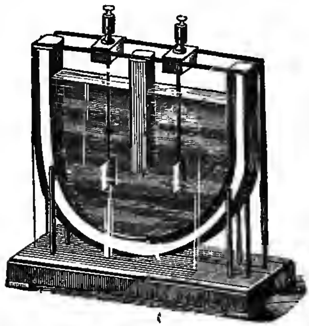


Woodhouse and Rawson's Battery or Dynamo Pole Indicator (*Full size*).

Messrs. Woodhouse and Rawson have produced a very handy pocket instrument for the purpose of finding the direction of a continuous current. It consists of a white transparent liquid contained in a glass tube, the ends of which are closed by metal stoppers. At the outside there are ordinary screw-terminals, to which the wires from the generator are to be attached. Inside the tube are two platinum wires with about half-an-inch or so of the liquid between them. On the passage of a current, the liquid is decomposed, and the **NEGATIVE** pole is at once covered with a *purple tinge* by the electrolysis of the liquid. The decomposed

substance is rapidly dissolved again by the liquid on the cessation of the current, and the white colour of the liquid restored.

Third, If you take a common tumbler, a double-necked bottle, or any convenient form of vessel, such as that shown by the accompanying figure, three-quarters filled with copper sulphate solution, and place therein two parallel small strips of clean, sand-papered lead, connected up to the leading wires from an electric generator; then, a few seconds after completing the circuit, the lead strip connected to the **NEGATIVE** pole of the generator will be observed to be coated with a thin film of bright-coloured copper. This forms one of the handiest and best methods of detecting the (—) pole of a dynamo, as well as of storage cells, when you wish to charge the latter by the former, for it is not always convenient, nor even safe, to pass an unknown strength of current through a short wire in order to apply the compass needle test. Pieces of platinum, copper, tin, zinc, or iron will serve the same purpose as the two strips of lead, but you will find the lead easier to obtain, shape, and clean. Instead of a copper sulphate solution, dilute sulphuric acid may be used. In this case the lead strip connected to the + pole of the generator is oxidised, and turns **Brown** when the current flows. In fact, the combination of two lead strips with sulphuric acid forms the elements of a small secondary cell, for you are simply producing the characteristic *brown*-coloured + plate of such cells when you send a current through them.



VOLTAMETER FOR OBJECTIVE DEMONSTRATION OF ELECTRO-CHEMICAL DECOMPOSITION AND DEPOSITION, OR FOR FINDING THE POLES OF A GENERATOR.

LECTURE XX.—QUESTIONS.

1. What is your notion of a voltaic current? (S. and A. Exam., 1874.)

2. How would you arrange an experiment for the decomposition of water by an electric current? Give a sketch of the arrangement, and show where the different components of the water would appear, and their relative volumes. (S. and A. Exam., 1880.)

3. Why is it necessary to use more than one Daniell cell in decomposing water?

4. Tell me what you understand by chemical combination and chemical decomposition, illustrating your remarks by reference to the formation and decomposition of water. (S. and A. Exam., 1874.)

5. Give me a good example of chemical combination and decomposition brought about by one and the same current. (S. and A. Exam., 1874.)

6. A piece of platinum is to be coated with copper by the help of a voltaic battery. Describe some arrangement that might be employed for this purpose. (S. and A. Exam., 1882.)

7. The current from a voltaic battery is passed at the same time through a thin wire and through dilute sulphuric acid, connected in series. What will happen to the wire and to the dilute acid, and what change (if any) will be produced in each case by reversing the battery connections, so as to alter the direction of the current through the wire and liquid? (S. and A. Exam., 1887.)

8. Plates of platinum and copper are dipped into a solution of copper sulphate. What effects are produced upon them if a current is passed through the liquid from the copper to the platinum? (S. and A. Exam., 1888.)

9. One end of a copper wire is fastened to the copper end of a battery, and one end of another copper wire is fastened to the zinc end of the battery. What happens if the other ends of these two wires are put side by side (but not touching) into a solution of sulphate of copper? (S. and A. Exam., 1886.)

10. Two copper wires, one connected with one terminal to a voltaic battery and the other connected with the other terminal, dip side by side, but without touching each other, into a solution of sulphate of copper. What happens to the immersed part of each wire? (S. and A. Exam., 1884.)

11. You have access to the terminal wires made of copper of a hidden battery. Explain how you would tell which wire was connected with the zinc and which with the platinum pole of the battery by observing what happens when the ends of the wires are dipped at the same time into the same vessel containing a solution of sulphate of copper (cupric sulphate). (S. and A. Exam., 1883.)

12. Describe by aid of sketches the process of electroplating or of electrotyping.

13. Two copper plates of the same weight are connected, one with the positive and the other with the negative pole of a voltaic battery, and immersed side by side in a solution of copper sulphate. If, after some time, the plates are removed, dried, and re-weighed, they are found no longer to weigh alike. Account for this, and explain how, by the continued action of the current, the equality of the plates could be re-established. (S. and A. Exam., 1890.)

14. When a plate of zinc and a plate of platinum, connected by a wire, are both dipped into the same vessel of dilute sulphuric acid, an electric current passes along the wire. State and account for the effect of moving one of the plates into a separate vessel of acid. (S. and A. Exam., 1881.)

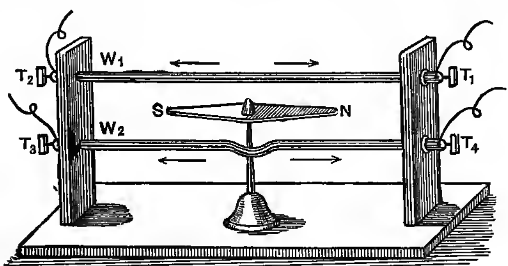
15. How are wires carrying a voltaic current usually insulated? What is the meaning of the word insulation? (S. and A. Exam., 1875.)

APPENDIX TO PART II.

PRACTICAL NOTES ON MAKING EXPERIMENTAL APPARATUS FOR STUDYING VOLTAIC ELECTRICITY.*

To Make an Oersted's Stand for Studying the Effects of Currents on a Magnetic Needle.—(1.) Read carefully over the following instructions, and then make a full size *side elevation and plan* (or a scale drawing with the full sizes marked thereon) of the accompanying perspective view of the apparatus.

(2.) Write out in a tabular form a detailed list of the different materials



AN OERSTED STAND.

required and their dimensions, leaving a reasonable margin for working the several pieces down to the sizes on your drawing.

(3.) Procure a piece of yellow pine for the base, and plane it down "fair and square" to say $14'' \times 6'' \times \frac{3}{4}''$.

N.B.—The simplest way to do this is—

1st, Plane one surface, say the bottom surface, perfectly flat; testing the truth of your work, by placing a straight-edge diagonally across each of the two opposite corners in turn, until you cannot see any light between the bottom line of the straight-edge and the surface of the board. *Mark this surface No. 1 with a pencil.*

2nd, Plane one of the longitudinal edges (*i.e.*, one of the edges in a line with the grain of the wood) straight and at right angles to surface No. 1, testing the truth of your work by a straight-edge and an ∟ square. *Mark this edge No. 2 with a pencil.*

3rd, Apply your ∟ square firmly to edge No. 2, so that the outer edge of the blade of your square is within $\frac{1}{8}''$ from one end of the base. With a sharp-pointed knife draw as deep and firm a line as you can right across the surface of No. 1 by pressing the blade of the knife uniformly to the outer edge of your ∟ square. Then, by applying the ∟

* Read the Preliminary Note to Appendix Part I.

square in a similar fashion to each of the remaining three sides, make an incision fair in line with your first incised line. The object of thus incising a line all round near one end of the board is, that it may act as a guiding-mark for you to plane up to. A mere pencil-line is easily passed over, but the deep cut of a knife will guide you, and prevent your snipping off a piece of the end-wood with the plane. Now make this end-edge truly at right angles to Nos. 1 and 2, testing the truth of your work by your ∟ square. *Mark this edge No.* 3.

4th, Scribe off with your knife the remaining end-edge in the same way as you did No 3, and plane it at right angles to Nos. 1 and 2. *Mark this edge No.* 4.

5th, With a carpenter's marking or cutting gauge, or with your foot-rule and knife, draw on the bottom and top surfaces a line parallel to No. 2 at 6″ therefrom. Plane this longitudinal edge parallel to No. 2 and at right angles to No. 1. *Mark this side No.* 5.

6th, With your carpenter's marking (or still better, a cutting) gauge set at $\frac{3}{4}$″, apply the same firmly to surface No. 1 all round its edges, so as to mark off a line parallel to the same. Plane this last surface down to the gauge-line, and make it perfectly flat, as in the case of No. 1 surface. *Mark this surface No.* 6.

7th, Round all the four edges of surface No. 6 to a radius of say $\frac{1}{8}$″, and sandpaper them smooth, as well as the top surface and sides (*i.e.*, Nos. 2, 3, 4, 5, and 6).

(4.) Procure two pieces of yellow pine, or still better mahogany, or other hardwood. Plane them down to $8'' \times 2'' \times \frac{3}{4}''$, and test the truth of your work in precisely the same way as recommended by the previous notes for the making of the base.

(5.) Procure two pieces of hard-drawn copper or brass wire about $\frac{1}{8}$″ diameter and 14″ long. Straighten one of them, W_1, and bend a half circle in the middle of W_2. Now cut them to exactly the same length, say 13″, and screw an $\frac{1}{8}$″ thread on each of the four ends to a length of $\frac{1}{2}$″, with a brass-pitched thread screw plate. Burnish these wires, W_1 and W_2, perfectly clean and bright, and lacquer them with brass lacquer, so as to keep them from oxidising.

(6.) Turn down from a $\frac{5}{8}$″ rod of hard brass four terminals, $T_1T_2T_3T_4$, of the pattern shown by the foregoing illustration, and about $1\frac{1}{4}$ inches in length over all. Before taking these terminals out of the lathe, drill a hole right through each of them, and tap them with an $\frac{1}{8}$″ tap, so as to fit the screws on W_1 and W_2, as well as the thumb-screws you are about to make from the same sized rod of brass. Take them out of the lathe and bore a small hole $\frac{1}{16}$″ or $\frac{3}{32}$″ through them, at right angles to the central brass screw thread, and about $\frac{3}{8}$″ centre from the outer end of the terminal. These small holes are for receiving the ends of the flexible leading wires from the battery. Turn down four pinching thumb-screws, with shanks $\frac{3}{4}$″ in length and $\frac{1}{8}$″ diameter screwed to fit the terminal's screw, and with round milled heads or with ▭-shaped filed heads, from the $\frac{5}{8}$″ brass rod which you employed for making the body of the terminals.

(7.) Take the two end vertical wooden supports and fix them firmly and fairly together. Bore two holes through them about $\frac{1}{8}$″ diameter, so as to fit W_1 and W_2 tightly, and about 2″ apart, keeping the top hole 1″ or $1\frac{1}{2}$″ from the top end of the wood.

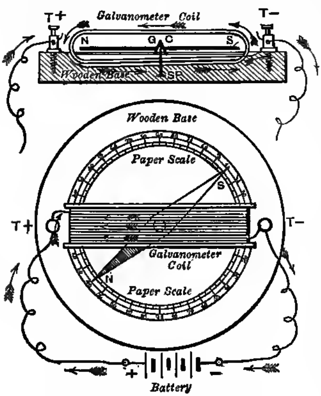
(8.) Mortise each of these wooden uprights half-way through the base, at about 1″ from the ends of the base, and fix each of them securely to the same by two brass screws $1\frac{1}{2}$″ to $1\frac{3}{4}$″ long, put in from the bottom or surface No. 1.

(9.) Unscrew one of these end pieces of wood and insert wires W_1 and W_2 into their holes in the other upright. Screw on terminals T_1 and T_4, and then insert the loose upright simultaneously into its place in the base with your inserting the other ends of W_1 and W_2 into their holes in this end piece. Screw on T_2 and T_3. Again screw home the bottom screws, and adjust both end-pieces until they stand firmly at right angles to the base.

(10.) Varnish the whole of the woodwork with the best shellac varnish, and paste a neatly printed label on the upper surface of the base, containing a description of the apparatus, and your name, with the date and the place where you made it.

(11.) Place a freely-poised horizontal test-needle (such as you made in accordance with the instructions in the Appendix to Part I.) on a stand, so that the needle is midway between W_1 and W_2, and perform all the experiments mentioned in Lectures IX. and X., which can be carried out with this simple and instructive piece of apparatus.

To Make a Detector Galvanometer.—(1.) Read over the following instructions, and make a full-size drawing of the accompanying sectional elevation and plan, which may be taken as drawn to a scale of 2 inches to 1 foot in the case of an instrument suitable for student's use, or for demonstrations before a small class.



DETECTOR GALVANOMETER.

(2.) Write out a tabular list of all the materials with their exact sizes, and procure the several pieces in the rough, just leaving sufficient margin to finish them to the required dimensions.

(3.) Turn in a lathe, or plane and spokeshave the wooden base from a piece of yellow pine or mahogany. Bore a small pin-hole through the centre of the base, then sandpaper, and give the top and edge two coats of shellac varnish.

(4.) Either (*a*) make a ▭-shaped wooden frame (as illustrated by the fifth figure in Lecture X.) from a piece of mahogany by aid of your plane, boring-brace, and chisel, with a shallow groove 1″ wide and $\frac{3}{16}$″ to $\frac{1}{4}$″ deep along the top, bottom, and ends, to contain the coil of wire, and a ▭-shaped hole 6″ long by 1″ deep, cut transversely through the frame to clear the magnetic needle, and permit of its swinging freely from one side to the other through this opening; or (*b*) construct a neat ▭-shaped brass frame with the same objects in view as (*a*), but having rounded ends and flanges, by aid of your brass-working tools and soldering bolt; or (*c*) plane a piece of wood to act as a mandril, say 8″ or 10″ long, 6″ broad and 1″ deep, with rounded sides, tapering slightly towards one end, and fit a wooden wedge 4″ or 5″ long by $\frac{7}{8}$″ deep into the centre of the tapered end, so as to press it out to the 6″ breadth when the wedge is driven home.

(5.) Suppose you adopt the latter plan, (*c*), as being the easiest and quickest, although perhaps not the neatest method in the end; obtain $\frac{1}{4}$ lb. or 90 feet of cotton-covered copper wire, No. 22 Standard Wire Gauge, *i.e.*, ·028″ diameter, and wind it tightly, closely, and neatly on the wooden mandril about 2″ from the tapered end, and with the wedge driven hard home. Apply either 15 turns along with 5 layers deep, or say 20 turns by 4 in depth, leaving out about 6″ of wire at each end for future attachment to the terminals. With a darning-needle pass a strong thread two or three times around this coil, and tie it firmly at six places, viz., at each end, and at about 1½″ from each end, top and bottom. Now varnish the outside layers of the coil with shellac varnish, giving it three or four coats, taking care to dry the varnish slowly before a fire after each coat.* Take out the wedge, press the tapered forked ends of

* This and the subsequent varnishings may be dispensed with if the student has sufficient skill to make a neat, compact coil. In which case, he should use

the wooden mandril together, and remove the coil carefully from the same. Varnish the inside of the coil several times, and remove the thread bindings if thought desirable. Finally, varnish the top and inside until the whole presents an even, shining, and solid appearance.

(6.) Place the coil centrally on the wooden base, and mark off the outline of the coil thereon. Gouge out a hollow seat in the base, about ½″ deep, to receive the lower half of the coil.

(7.) Draw a scale upon stout white drawing-paper or upon thin white cardboard, and divide it off as shown by the figure. Fit this scale-card into the coil, and glue both it and the bottom of the coil centrally to the wooden base.

(8.) Buy or make (see last Note) two brass terminals, T+T−, of the form shown by the above sketch.

(9.) Bare each of the free ends of the coil, scrape or emery-cloth them clean, as well as the underneath sides of the terminal flanges. Screw the tongues of the terminals half-way into the base, pull the free ends of the wires tight, twist the bared parts twice round the screws of the terminals, and screw the terminals hard home to the base, so as to produce good electrical contact between each terminal and one end of the coil.*

(10.) Force a darning-needle or steel pin, SP, from behind through the previously made central pin-hole in the base, until it protrudes through the scale sufficiently far to support the magnetic needle midway between the upper and lower inside turns of wire of the coil.

(11.) Support the base by levelling it upon two blocks of wood or upon two books, so that the protruding eye-end of the darning needle does not touch the table, and try on a magnetic needle, NS, with glass Λ centre GC (made in accordance with directions already given in Appendix to Part I. at page 73), until you get it so adjusted that it swings evenly and freely over the scale and midway between the inner sides of the coil. When this has been done, snip off the darning-needle close to the bottom side of the wooden base.

(12.) Should you desire to test the effect of passing a current through 1, 10, 20, 40, 60, or any previously arranged number of turns of wire as compared with the total number, then it will be necessary when winding on the wire to the mandril or ⊓-shaped bobbin, to attach by binding and soldering a T piece of wire to the wire of the coil at the under side of the end which will finally be the outer end of the coil, when you come to these turns, and to insulate these joints with shellacked or paraffined paper. The free ends of these T pieces can then be fixed to separate terminals arranged equidistantly on the wooden base, with numbers close to them marked on the upper side of the base, indicating the respective number of turns of wire in circuit with them and the single terminal attached to the inner end of the coil which is situated at the other side of the base.

(13.) In addition to merely using this instrument as a detector and indicator of the direction of currents, the student, when he has mastered Ohm's Law (as explained in the last three or four Lectures of Part II.), should endeavour not only to calibrate his galvanometer into milliamperes ($\frac{1}{1000}$th ampere), but also to plot out a curve showing the relation subsisting between the deflections in degrees of arc and the current strength in milliamperes. This may be

blue coloured cotton or blue silk covered wire, tying the several layers together with this blue covered wire or blue thread, as they look neater than white. The whole coil may then be tied firmly to the wooden base, instead of glueing it thereto, by taking a turn or two of the wire of which the coil is composed ⊥s round the same and through two holes in the base near each end of the coil.

* In the finer kinds of electrical instruments it is *absolutely* necessary to solder the ends of the wires to the terminals. This might be done in the present case if the terminals were made with a shank to pass through the base, and fitted with a nut to screw them firmly to the same.

done in various ways, the simplest being to procure from the laboratory a standard tangent or delicate ampere galvanometer (the values of the deflections of which are accurately known), and to join up this instrument in direct circuit with his own one (placed with coil and needle in the magnetic meridian), a battery, and an adjustable resistance. By varying the adjustable resistance until the standard instrument reads 1, 2, 3, &c., milliamperes in succession, and marking in red ink on the inner or outer circle of the scale of the detector galvanometer these several figures as the needle is deflected under the action of the corresponding currents, you obtain a milliampere scale.* To plot out the curve, take a piece of squared paper;† mark some convenient point near the left-hand corner as a zero or 0. Divide off the deflections along the vertical line and the milliamperes along the horizontal line from this zero point. Draw horizontal lines from each of the deflection marks, and vertical lines from each of the milliampere marks. Where the deflection lines cross the corresponding current lines make a ×, and draw a curve through these crosses. This forms the characteristic curve of your instrument, and shows you graphically how the deflections vary with the current.

To Make a Solenoid.—Reference has frequently been made in Part II. of this book to the uses and action of solenoids; for example, in Lectures XII., XIII., and XIV. Since the teacher may desire his students to make one or more sizes of solenoids wherewith to illustrate his experiments, or even to make a mirror galvanometer coil, and seeing that it will pave the way for our description of how "to make an electro-magnet," it has been thought advisable to give the following practical notes regarding the different operations that must be attended to in designing and constructing this simple and useful piece of apparatus.

(1.) Determine the precise uses to which you wish to put the solenoid.

(2.) After reading over the following instructions and making the necessary calculations, draw a full-size sectional elevation and plan of the solenoid, and write out a table of the different materials required with their sizes.

(3.) Ascertain as nearly as you can the maximum current in amperes which, with the battery or dynamo E.M.F. at your disposal, you can pass through or are likely to require to pass through the solenoid wire, in order to effect the objects in view.

(4.) Fix upon the size of wire to carry this current, remembering that the magnetisation produced along the axis of the solenoid is directly proportional to the ampere-turns of wire on the solenoid, *i.e.*, to the product of the amperes and the total number of turns of wire. **For example,**—the same magnetic effect will be produced by 10 amperes flowing 100 times round the core as by 1 ampere flowing 1000 times round it. If you have only a few accumulator cells or a battery of low internal resistance, capable of producing a difference of potential of say 10 volts at the terminals of the solenoid, then (by Ohm's Law) in order to obtain a current of 10 amperes through your solenoid coil, its

* For other methods, teachers may refer to Munro and Jamieson's "Pocket-Book," or to "Practical Notes for Electrical Students," by Kennelly & Wilkinson, published by the *Electrician* Printing and Publishing Co., or to Professor Ayrton's "Practical Electricity," published by Cassells & Co.

† See the squared paper bound at the beginning of Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables," or squared foreign note-paper will do. Also refer to the curves under the heading of Dynamos, p. 380, &c., and Curves of Magnetisation, p. 441, in the "Pocket-Book," in order to get a better idea of the manner of plotting them.

resistance must not exceed 1 ohm. Now a No. 16 S.W.G. copper wire will carry 10 amperes in the case of a solenoid which is only used for a short time without overheating it. Further, about 400 feet of this wire gives a resistance of 1 ohm.* This determines the diameter and length of wire, and, from what follows, you will be able to decide upon the dimensions of the bobbin to contain this length of wire. For *small solenoids* or *electro-magnets*, such as students are likely to make, there will be no fear of injuring the insulating cotton covering of the wire if a current be passed through it at the rate of 3000 amperes per square inch (or say 4 amperes per square millimetre) cross section of the wire.

Thus a	No.	10	S.W.G.	wire will	safely carry	36	amperes.
"	"	12	"	"	"	27	"
"	"	14	"	"	"	15	"
"	"	16	"	"	"	10	"
"	"	18	"	"	"	4	"
"	"	20	"	"	"	3	"
"	"	22	"	"	"	2	"
"	"	24	"	"	"	1	"

If you can command the current strength, it will of course be cheaper, as far as the solenoid alone is concerned, to adopt a large size of wire with few turns and pass a strong current through it, rather than to use a long length of fine wire with a weak current. The following dimensions of three pairs of solenoids made by the author's students may be of service, since, having been made in duplicate, they serve for slipping on to electro-magnet cores when required for the magnetisation of steel bars, as well as for demonstrating many other useful tests in connection with the effects of electro-magnetism. The various letters have the same signification as in the following figure and formulæ :—

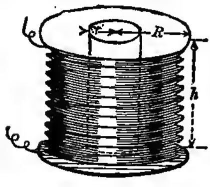
DIMENSIONS OF SOLENOIDS.

		No. 1.	No. 2. ▭ Wire.	No. 3.
r	=	·85″	·85″ "	·5″
R	=	1·6″	1·6″ "	·9″
d	=	·082″	·128″ (equivalent d)	·066″
h	=	5·9″	6″	4·3″
L	=	500′	157′	85′
n	=	9	9	6
N	=	790	234	380

(5.) Having determined the diameter and length of the wire you intend to use, you next obtain a specimen of the same, double covered with cotton. Measure the diameter outside the cotton with a micrometer screw-gauge, and then ascertain by aid of the following sketch, formulæ, and example the dimensions of the bobbin that will contain it. Further, before purchasing the length required, you had better measure carefully an exact length of the wire, and cut off, say, 3 to 5 feet of it, and weigh it most accurately. Then calculate what will be the weight of the total length required, or the length per pound weight, because wire is generally sold by the pound in this country, and the weight tables of covered wire vary considerably. In any case, the exercise will be a useful and interesting one.

* Tables of relative dimensions, lengths, weights, and resistances of copper wire, 7th edition, Rankine's "Rules and Tables," p. 350, or Munro and Jamieson's "Pocket-Book," p. 220.

Filling a Circular Bobbin with Round Wire:—



Let r = radius of bobbin core.
R = " " outside.
d = diameter of wire outside insulating covering.
h = height or length of bobbin between inside of flanges.
L = length of wire on bobbin (with very close winding).
n = number of turns of wire in a section.
N = " " on bobbin.

N.B.—*The signs r, R, d, h, and L must be taken in the same unit, feet, inches, or centimetres.*

Then

$$\mathrm{L} = \frac{\pi h}{d^2}(\mathrm{R}^2 - r^2);\quad n = \frac{\mathrm{R} - r}{d};\quad \mathrm{N} = \left(\frac{\mathrm{R} - r}{d^2}\right)h.$$

Example.—Suppose that we have a bobbin of the following dimensions:—$r = 1''$, $\mathrm{R} = 2''$, $h = 6''$, and that we wish to wind upon it No. 14 S.W.G. wire (0·08″ diameter) covered with double-lapped very fine cotton, which measures outside the covering $0{\cdot}1'' = d$;* what length of wire, L, will the bobbin hold with close tight winding?

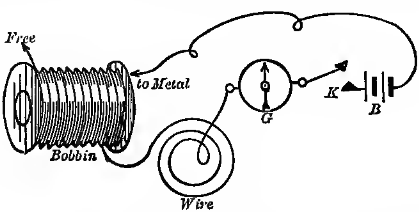
$$\mathrm{L} = \frac{\pi h}{d^2}(\mathrm{R}^2 - r^2) = \frac{\pi \times 6''}{{\cdot}1^2}(2^2 - 1^2) = \frac{3{\cdot}1416 \times 6}{{\cdot}01}(4 - 1) = 5654{\cdot}88 \text{ inches} = 471{\cdot}24 \text{ feet.}$$

And,

$$\mathrm{N} = \left(\frac{\mathrm{R} - r}{d^2}\right)h = \frac{2 - 1}{{\cdot}01} \times 6 = 600 \text{ turns.}$$

(6.) Make your bobbin either by turning and boring it from a piece of well-seasoned hard wood or by soldering turned brass flanges on to a brass tube. If you adopt the latter method, varnish the outside of the brass tube and inside of the brass flanges. Should the solenoid be required to carry intermittent or alternate currents, then you must run a saw-drift right along one side of it, and insert a piece of insulating paper along the slit, so as to prevent induced currents being generated in the brass tube every time the current changes strength or direction (see Lecture XVII.).

(7.) When winding the wire on the bobbin, be sure that you note most carefully the number of turns in each layer, the number of layers, and consequently the total turns, N, which number will afterwards have to be marked



upon the outside of the bobbin, since it has always to be multiplied by the current strength in amperes when determining the strength of magnetic field evoked by the current.

* Double cotton-covered wire, for all practical purposes, may be taken as increasing the diameter of a wire by ·02 inch.

(8.) When coiling wire upon any metal bobbin for an electro-magnet, &c., always keep on a *continuous* insulation resistance or non-conductivity test, as per above sketch. The inner end of wire is "free" or insulated, the outer end being joined to a sensitive galvanometer, G, capable of detecting the slightest fall in insulation resistance, when kept in circuit with battery, B, by means of the key, K.

(9.) Varnish the outside layers of the solenoid in the manner described under the note on making a detector galvanometer.

(10.) Fix the bobbin to a flat wooden base fitted with two brass terminals, and solder the ends of the wire to the terminals,* or fix a piece of hard wood between the flanges and attach the terminals to this piece of wood. The latter plan will be found most convenient if the solenoid is to be used in connection with iron cores to form an electro-magnet.

* See fig., p. 149.

To Make an Electro-Magnet.—(1.) Ascertain exactly what your electro-magnet is required to do, whether for the purpose of magnetising steel bars, as illustrated at pages 6 and 72, Part I., or for a Morse sounder (page 42, Part I.), or for an electric bell, page 129, Part II.), or merely for attracting a keeper, with weight attached, as shown at page 127, Part II.

(2.) Draw in sectional elevation and plan the iron cores, remembering that the greater the diameter of the cores, the shorter their length, and the nearer they are together, the less will be their magnetic resistance, and consequently, if made of the best soft Swedish iron, the greater will be the strength of the magnetism evoked in them by a certain number of ampere turns. In the case of the electro-magnet illustrated at pages 6 and 72, Part I., the iron cores are simply round pieces of soft Swedish iron screwed hard into a flat piece of the same kind of iron. The cross area of the yoke, Y, should never be less than the cross area of the cores; in fact, it is advisable to make it $1\frac{1}{2}$ times or twice as great. The cores should protrude at least $\frac{1}{2}''$ above the ends of the solenoid coils if the electro-magnet is to be used for magnetising bars of steel, in order to prevent damaging the flanges or the insulation of the wire.

(3.) Determine (as in the case of the solenoid) the size of wire and the number of turns which you can put on to the bobbins, or which you can wind directly upon the iron cores, should you decide to dispense with bobbins.

(4.) Wind the wire on the two limbs of the core as if it were one continuous length of iron, *i.e.*, don't change the direction of the winding. If you elect to use bobbins, then join them up so that the current will produce a **N**-pole at one end and a **S**-pole at the other. From the very full directions given in Lecture XIV., the student will have no difficulty in joining up the solenoid coils correctly.

(5.) As an example of a cheap and easily-made electro-magnet for the purpose of enabling students to magnetise their steel bar magnets, as well as for performing most of the ordinary electro-magnetic effects that are required of such an instrument before a class, we give the following dimensions:—

Dimensions of Electro-Magnet.

Diameter of cores $= \cdot 9''$; length of cores $= 4\cdot 5''$; distance between the centres of cores $= 3''$; sizes of yoke $= 5\frac{1}{2}'' \times 1'' \times \frac{1}{2}''$; size of copper wire = No. 16 S.W.G. double covered with cotton; number of layers of wire wound direct on each core limb $= 4$. The cores protrude about $\frac{1}{2}$ inch above the winding, and the yoke is screwed firmly to a strong hard wooden base. Such an electro-magnet will lift 60 lbs. attached to its keeper when a current of 12 amperes is passed through its wire, if the cores and yoke are of soft wrought iron.

(6.) As an example of a cheap and easily-made electro-magnet for a small trembling bell, we give the following dimensions :—

DIMENSIONS OF ELECTRO-MAGNET FOR A HOUSE BELL.

Diameter of cores = ·4″ ; length of cores = 1·7″ ; distance between centres of cores = 1″ ; length inside wooden bobbin flanges = 1·5″ ; inside diameter of winding = ·5″ ; outside diameter of winding = ·8″ ; No. of bare copper wire = 24 S.W.G. (double silk covered). Total length of wire on both bobbins, 210 feet; number of turns on each bobbin, about 600; total resistance, 4·67 ohms. Two old Leclanche cells, giving a P.D. of 1·4 volts when joined in circuit with the bell, ring the same satisfactorily, so that the electro-magnet requires about ·03 ampere (30 milliamperes) to attract the armature with the necessary force and rapidity.

Final Remark to Part II.—If a student has thoroughly mastered the foregoing "practical notes," and has successfully made the apparatus described, he should be encouraged to try his hand at some of the other appliances illustrated in Part II. The author will feel much obliged to teachers and students for hints as to which of the various educational models they think should be described in the Appendices to the next edition.

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APPENDIX TO PART III.

ELEMENTARY MANUAL

OF

MAGNETISM AND ELECTRICITY.

PART III.

FRICTIONAL ELECTRICITY, OR ELECTRO-STATICS.

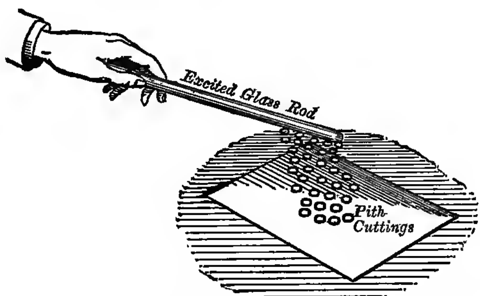
LECTURE XXI.

CONTENTS.—Early History of Electricity and Derivation of the Word—Electrification by Friction—Electrification and Attraction—Necessity for Keeping Apparatus Dry and Warm—Drying and Warming Tray and Hot-Water Oven—Electrical Repulsion—Questions.

Early History of Electricity and Derivation of the Word.—About 2500 years ago (600 B.C.), a Greek philosopher, Thales of Miletus, observed that the fossil gum amber, when rubbed with woollen substances, became imbued with the peculiar property of attracting light bodies. The Greek word for *amber* is ἤλεκτρον (*electron*), from which the English word "*Electricity*" was naturally derived, since the attractive force possessed by the amber when subjected to friction remained an isolated fact for 2200 years. In the year 1600, Dr. Gilbert of Colchester, physician to Queen Elizabeth, discovered that many other substances besides amber (such as glass, sulphur, sealing-wax, resins, &c.), when suitably rubbed, became similarly endowed with an attractive force for other bodies. Since then, it has been proved that whenever *any* two unlike surfaces are rubbed together, or brought into contact and separated, the peculiar excitation or *electric state* is caused. Bodies when in this condition are said to have an *electric charge*, or to be in a state of *electrification*, in virtue of which they exhibit between themselves and other bodies in a similar state certain stresses other than those due to ordinary mass or molecular attraction.

As we shall see later on, the electrification or electric charge of a body may be accurately measured and dealt with as a physical quantity.

Electrification by Friction.*—When a surface of one body is rubbed over a surface of another body, the mechanical resistance termed *friction* is set up between the surfaces in contact. This friction opposes the motion; consequently, force has to be applied to continue the rubbing, and so much work is said to be spent or done on the operation. In the case of identically like surfaces, the work done in overcoming the friction is directly and wholly converted into another form of energy called *heat*, without the slightest sign of electrification. When, however, any difference (chemical, structural, or thermal) exists between the rubbing surfaces, then part of the work done goes to produce electrification of both surfaces. If the conditions are suitable, this electri-



ATTRACTION OF LIGHT BODIES BY AN ELECTRIFIED GLASS ROD.

fication may be rendered apparent; but the quantity of electricity thus produced varies so much with the nature and condition of the surfaces, that no proportion has yet been found between work done and the electrification produced.†

Electrification and Attraction.—EXPERIMENTS I.—(1.) *Glass rod rubbed with silk attracts light bodies.*—Spread upon the lecture-

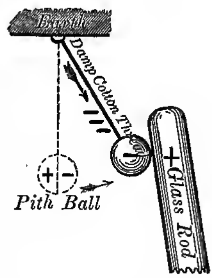
* In some elementary books on electricity, "FRICTION" is stated to be "the act of rubbing." We prefer to adopt the sense in which it is used by engineers, viz., the natural resistance or opposition to rubbing, whereby always heat, and, under favourable circumstances, electricity are produced.

† It does, however, seem reasonable to infer that when electrification is produced and retained on the surfaces, a proportionately smaller quantity of heat will be generated for the expenditure of a certain number of units of work, since we cannot evoke energy of one form (whether mechanical, chemical, thermal, electrical, or magnetic) without an equivalent disappearance in the quantity or physical value of one or more of the other forms.

table, or lay upon a blackened sheet of tin or an ordinary tea-tray, thin cuttings of elder pith, small pieces of tissue paper,* light feathers, or dry sawdust. Bring near these several light bodies an *unrubbed, dry, warm* glass rod. Not the slightest sign of attraction takes place between the glass rod and the pith, paper, feathers, or sawdust. Now rub the glass rod vigorously with a dry, warm piece of silk,† and again present it to the light bodies. You observe that they appear quite lively, rising through a distance of several inches to the glass rod, dancing up and down to and from it in rapid succession, thus proving that the rod has been electrified.

(2.) *Sealing-wax, &c., rubbed with flannel attracts light bodies.*—Repeat the above experiment on the light bodies with rods of *dry warm* sealing-wax, resin, ebonite, sulphur, rubbed with a *dry warm* flannel pad or the fur of a cat. In each case attraction takes place between the electrified rods and the light bodies.

(3.) *Electrified rods attract an empty egg-shell.*—Make two small holes in the extreme ends of a hen's, turkey's, or goose's egg. Blow out the contents and lay the empty egg-shell on the lecture-table. Rub any one or other of the above-mentioned rods, as stated under (1) and (2), and bring it near the egg-shell. Slowly withdraw the rod parallel with the table, and the egg-shell will roll along the table after it.



ATTRACTION OF PITH-BALL; BALL ADHERES TO ROD.

(4.) *Electrified rods attract a suspended pith-ball.*—Rub every one of the above-mentioned rods, as previously directed, and present them in turn (immediately after being rubbed) to an elder-pith ball (or to a small empty egg-shell such as a sparrow's) suspended from a hook or other support by a fine thread. The ball will be attracted from the perpendicular, as shown by the accompanying illustration.

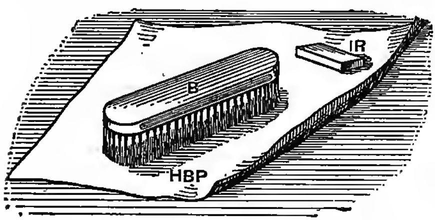
(5.) *Attraction of a long wooden lath.*—In order to exhibit this fundamental phenomenon of attraction successfully to a large audience, take a wooden lath about 6 feet long, and balance it on a fine needle-

* The punchings from the white paper strip used in the transmission of messages by the Wheatstone form of telegraph instrument answer the purpose very well. They may be got from any General Post-Office.

† A pad covered with silk having its surface spread over with a thin layer of *amalgam* gives the best results. See Appendix at the end of Part III. as to how to make amalgam and fix it on the silk-covered pad.

point by a glass Λ centre.* Present to an end of this lath any of the above-mentioned rods duly excited by rubbing, and you will find that the lath will be attracted to the charged rod through great distances. By a little skilful manipulation, the lath may be set spinning round and round its centre at a great rate, without ever bringing the charged rod nearer to it than a few inches. A dry warm ebonite comb drawn a few times through the hair of the head or beard will be so excited as to cause the lath to follow it with apparently magical celerity.

(6.) *Attraction of light bodies by rubbed paper.*—On a *dry hot* drawing-board lay a sheet of *dry hot* brown paper, HBP, and brush it vigorously with a *dry* warmed clothes-brush, B, or with a piece of *dry* warm india-rubber, IR.



Electrification of Hot Brown Paper by a Hair Brush or by India-Rubber.

(*a.*) Fold the paper with the brushed or rubbed side kept outside. Present this outside in turn to the light pieces of paper, &c., to the suspended pith-ball, and to the balanced lath. You observe that they are severally attracted towards the excited paper.

(*b.*) Again warm the board, brown paper, and brush. Brush the paper as before. Lift the paper by one corner and bring it near the wall of the room or the black board. It leaves the hand and sticks to wall or board with considerable tenacity until the electric charge has disappeared by leakage to and from earth. The drier the wall and the air of the room, the longer will the paper adhere, because there is less opportunity for the electricity to leak to and from earth.

(*c.*) Excite the paper once more, and folding it, hold it above a student's unoiled head. The hairs of his head will immediately stand up, being attracted by the electrified paper.

Many other similar experiments will suggest themselves to teachers and students, but the few just mentioned serve to prove that certain dry warm substances, when rubbed by certain other unlike substances, become charged with electricity, and in consequence thereof the electrified bodies attract and are attracted by unelectrified bodies.

* See p. 239 and the Appendix to Part III. for figure and how to make this lath.

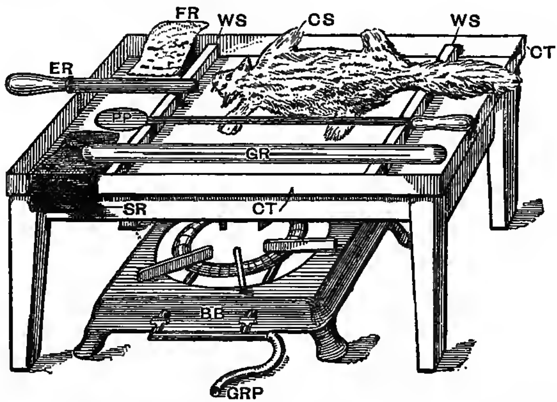
Necessity for Keeping Apparatus Dry and Warm.—In all the foregoing experiments the student will have noticed that particular attention was necessary to keep the several substances that were to be rubbed as well as the rubbers *dry and warm;* for if they were allowed to cool down to the temperature of the room, they would not act nearly so well, and in the case of the glass rod and the brown paper perhaps no attraction would be observable, however hard they were rubbed. The reason of this lies in the fact that, in the normal condition of our atmosphere, it is laden with moisture, which rapidly condenses on the surface of the apparatus, unless the surface be kept a few degrees higher in temperature than the surrounding atmosphere. A very thin film of moisture, although it may be quite imperceptible to ordinary observation, serves to conduct the electric charge to earth as soon as it is generated.

Experiments on Frictional Electricity may often succeed perfectly previous to a class or an audience assembling, but unless the greatest care be taken to keep the several appliances dry and warm *during* the demonstrations, much disappointment and vexation will result from unsuccessful attempts to produce the expected results owing to condensation from the moist breath of the observers. Frictional Electricity experiments succeed best in frosty weather, when the atmosphere is naturally very dry; but in any case, a teacher should never be without the means of quickly and easily rendering and keeping his instruments and other things dry and warm.

Drying and Warming Tray and Hot-Water Oven.—The following figure represents a simple and cheap form of drying and warming tray that the author has found answer the purpose very well. If necessary, it can be supplied with a semicircular or a flat cover of sheet-tin or copper, upon which the pieces of flannel and fur may be placed, without liability to becoming singed. The heat is also more perfectly retained by such a cover.

Another and very handy means of keeping the smaller experimental things dry and warm is to put them inside a horizontal hot-water oven, consisting of a thin copper case of □-rectangular section, surrounded by another and larger one, with a space of from one to two inches between them. This space is filled with boiling-water through a conical funnel and tap, situated on the top of the outer case at one end. A cock for letting out the water when cold into a pail or sink is fitted to the same end or to one side at the bottom. One end, two sides, and the bottom should be well lagged with felt, sheet asbestos, or other convenient non-conductor of heat. The top may be left bare in order to place thereon the silk, flannel, and fur rubbers. A hinged lagged

door may conveniently be fitted to the open end of the case. On opening this door, the glass, sealing-wax, ebonite, and other rods, as well as insulating supports, may be introduced and laid on wooden shelves or racks. The heat from the warm water cannot readily escape by the lagged bottom, sides, and end, but it easily passes through the thin inner copper case, and thus keeps the air inside and the various articles dry and warm for the time required to demonstrate the experiments. It also passes through the top and keeps the rubbers dry.



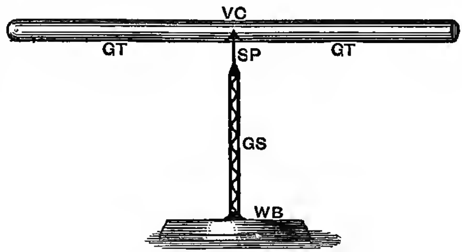
Drying and Warming Tray for Frictional Electricity Apparatus.

Index to Parts.

BB	represents	Bunsen burner.
GRP	,,	Gas rubber piping.
CT	,,	Copper tray.
WS	,,	Wooden supports.
GR	,,	Glass rod.
SR	,,	Silk rubber.
ER	,,	Ebonite rod.
FR	,,	Flannel rubber.
CS	,,	Cat-skin.
PP	,,	Proof-plane.

Electrical Repulsion.—You observed when we were demonstrating the attraction between a rubbed glass rod and light bodies laid on the table, that these light bodies after they touched the glass rod (and thus became charged with its electrification) were repelled and darted off from it. This proves that similarly charged bodies repel each other. This effect can, however, be better exhibited to a class in the following manner.

EXPERIMENTS II.—(1.) *Similarly rubbed pieces of glass repel each other.*—Take a thoroughly clean, dry, warm glass tube, having one end sealed, and a Λ centre formed at the centre of the tube so that the whole balances evenly on an insulated needle-point, as shown by the following figure.* The tube will revolve freely on the steel point under the action of a very small force. Now rub the glass tube from near the Λ centre to the closed end with the amalgamated silk rubber, holding the other end in the other hand. Place the tube on its balancing point, and then rub a dry, warm, glass rod with the *same* rubber. Bring the rubbed end of the latter near to the rubbed end of the former. You observe that the balanced tube is at once forced away from the glass rod, thus proving that the electrifications due to similarly rubbed pieces of glass repel each other. By skilfully keeping the glass rod always within an inch or two of the receding glass tube, you may produce very rapid rotation of the latter.



BALANCED INSULATED GLASS TUBE.

GT represents Glass tube.
VC ,, V centre.
SP ,, Steel point or supporting point.
GS ,, Glass stem (for insulating GT).
WB ,, Wooden base.

(2.) *Similarly rubbed pieces of ebonite, sealing-wax, or resin repel each other.*—Take a rod of ebonite, furnished with a Λ glass centre, and balance it on an insulated fine steel point, exactly in the manner illustrated by the last figure.† Rub one end of this rod with the flannel pad or cat's fur, and place it on the support. Rub one end of another ebonite rod with the same rubber, and bring that end near the rubbed end of the balanced rod. You observe that repulsion takes place between the two electric charges by the moving away of the balanced rod.

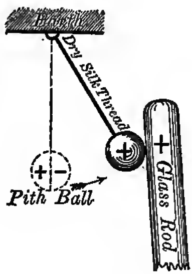
(3.) *Any insulated suspended light body charged by an electrified*

* See Appendix as to how to make this balanced tube and stand, as well as balanced ebonite or other rods.

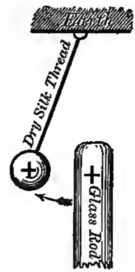
† Balanced rods of sealing-wax and resin are so very liable to be broken when glass Λ centres are fixed in them, that it is preferable to suspend them on a stirrup by a *silk* thread, in the same way as the hard steel bar is suspended in the figure, p. 2, Part I.

body is repelled by that body.—Take any light body, such as a pith-ball or a sparrow's egg, and suspend it from a hook or stand by a fine *silk* thread.*

Now, bring any electrified body near the ball. The latter is first attracted towards the former (as we saw in Experiments I., Case 4); and then, if the ball be permitted to touch the electrified body, a part of the charge is imparted to the ball. The two similar charges (the one on the ball and the other on the rod)



ATTRACTION BEFORE CONTACT.



REPULSION AFTER CONTACT.

now repel each other. The ball, being light and free to move, recedes from the rod, and if the latter be made to follow the former, the ball will keep at a respectful distance from the rod until the charge has been cancelled (by leakage to and from the earth), when it will be again attracted, recharged, and repelled as before.

* We use a *silk* thread in this case because silk is a good insulator, and will prevent the charge imparted to the ball from leaking quickly to earth. This fact will be readily understood by students from what they were taught in Part II., Lecture XIX.

Lecture XXI.—Questions.

1. From what is the word "electricity" derived? Describe the substance with which the first electrical effects were observed, and describe also the mode of exciting it. (S. and A. Exam., 1875.)

2. What do you understand by the terms "friction" and "frictional electricity"? In what forms do the work spent in rubbing two like and two unlike substances reappear?

3. You are required to electrify strongly a glass tube; how will you do it? You are required to electrify strongly a tube of gutta-percha; how will you do it? (S. and A. Exam., 1875.)

4. Supposing you were required to develop statical electricity and to prove its existence, how would you do it? (S. and A. Exam., 1878.)

5. How would you show that an unelectrified body is attracted by an electrified one?

6. Of what is the amalgam composed with which silk rubbers are covered? How is it made and applied?

7. A rod of sulphur is rubbed with flannel and then placed in a stirrup and hung up by a thread. Explain the behaviour of the sulphur when the hand is brought near to it. (S. and A. Exam., 1890.)

8. If upon a warm board a dry sheet of paper be rubbed with india-rubber, it is electrified. How is this proved? (S. and A. Exam., 1872.)

9. What is the action of two electrified glass tubes upon each other? What is the action of two electrified gutta-percha tubes upon each other?

10. A sheet of paper well dried and rubbed with a dry brush will adhere to the wall of a room. It will, however, remain longer in this position if the wall and the atmosphere are dry than if they are damp. Explain the reason for the difference.

11. How is it that in damp weather any ordinary electrical machine will not work well? (S. and A. Exam., 1883.)

12. How would you propose to keep frictional electrical apparatus dry and in good working order when the air is damp?

13. A stick of sealing-wax is rubbed with dry flannel and held over a pith-ball lying on a table. The ball rises to the sealing-wax and then falls again. Why does it rise, and why does it fall? (S. and A. Exam., 1882.)

14. Hair when brushed in dry weather is sometimes heard to crackle. Why is this, and why is the phenomenon only observed when the weather is dry? (S. and A. Exam., 1891.)

LECTURE XXII.

General Explanation of the Terms "Positive" and "Negative."—In the previous lecture we proved by experiments:—

First, That the electrification of a substance by friction produced attraction between it and any neutral or unelectrified body.

Second, That identically similar bodies, when rubbed by the same or identically similar rubbers, repelled each other.

Third, That bodies electrified from the same charge repelled each other.

We shall now prove that electrification is of two kinds, called respectively *positive* (represented by the sign + (plus)) and *negative* (represented by the sign − (minus)). The student who has read Part II. will be familiar with these terms and signs. The term "positive," with its sign +, has hitherto been used by us to indicate a potential or pressure above or greater than that of the earth (considered as zero or 0); whilst the term "negative," with its sign −, has been employed to indicate a potential of pressure below or less than that of the earth. In the case or such sources of electrical energy as the Voltaic battery or the magneto-electric machine, we proved that when the circuit was closed or completed, an electrical current passed throughout the circuit. We agreed to consider that the direction of the flow took place from a positive pole or place of higher potential to a negative pole or place of lower potential. Although we shall have to deal for the most part with fixed or static charges of electricity in this section of the subject, we will strictly adhere to this convenient, yet purely arbitrary, use of the terms positive and negative, both in regard to their potential and to the direction of flow when connected with other charges or with the earth.

Positive and Negative Electrifications.—EXPERIMENTS III.—(1.) Referring back to Experiments II., Cases (1) and (2), and using the same apparatus: rub the two pieces of glass with amalgamated silk, and you find, as before, that they repel each other. Rub the two pieces of ebonite with flannel, and you find that they also repel each other. Now rub the glass tube, balance it on its Λ centre, bring forward the ebonite rod freshly rubbed, and you observe strong attraction takes place between them. Rub the other ebonite rod, balance it on its Λ centre, bring forward the glass rod freshly rubbed, and you observe strong attraction takes place.

These experiments demonstrate that there are two kinds of electrification:—

(i.) *The electrification of glass rubbed with amalgamated silk.*
(ii.) *The electrification of ebonite rubbed with flannel.*

Further, these experiments prove that—

Glass rubbed with amalgamated silk ← Repels → *Glass* rubbed with amalgamated silk.

↘ ↙

Attracts Attracts

↗ ↖

Ebonite rubbed with flannel ← Repels → *Ebonite* rubbed with flannel.

It has been agreed upon by physicists and electricians to call the electrification of *glass* rubbed with amalgamated silk *positive* (or plus, +) electricity, and that of *ebonite* rubbed with flannel *negative* (or minus, −) electricity.* Hence we may express the results of the foregoing experiments in the following manner:—

Positive Electricity ← Repels → *Positive* Electricity.

↘ ↙

Attracts Attracts

↗ ↖

Negative Electricity ← Repels → *Negative* Electricity.

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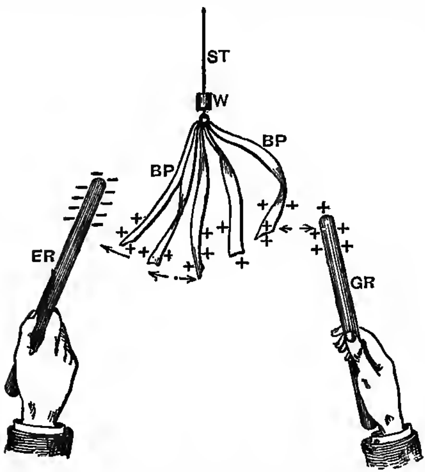
* We shall prove later on (in our more Advanced Book), by experiments with the condensing gold-leaf electroscope, as well as with a delicate electrometer, that the electrification of *glass* rubbed with amalgamated silk is *identical* in kind with that obtained from the free *copper* pole of a Daniell cell or

Or, **First Law**, *Like charges repel, but unlike charges attract each other.*

(2.) We shall now prove the above statements by another very simple and effective experiment. Take a sheet of *very* thin, dry, hot brown paper (or, still better, tissue paper), attach a silk thread with a small weight to the paper, and electrify the paper by rubbing it with a clothes-brush or a piece of pure black india-rubber in the manner already explained and illustrated (see Lecture XXI., Experiments I., Case 6). Cut the paper quickly with a sharp knife into narrow parallel strips, and suspend it from a hook or stand by the silk thread, as shown by the accompanying illustration. You observe that the strips of paper diverge from each other at their ends, because they are all charged with electricity of like kind.



LIKE CHARGES REPEL, BUT UNLIKE CHARGES ATTRACT EACH OTHER.

ST	represents	Silk thread.
W	„	Weight.
BP	„	Brown (thin) or silk paper.
GR	„	Glass rod.
EB	„	Ebonite rod.

Now, *First*, Bring forward towards the strips a glass rod rubbed with amalgamated silk. The paper is repelled. We at once conclude that the paper is positively charged because we know that the glass rod is positively charged.

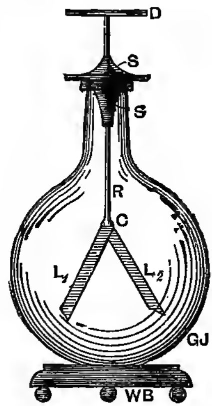
Second, Bring forward towards the strips of paper an ebonite rod rubbed with flannel. The paper strongly attracts and is attracted by the charge on the ebonite. This to a certain extent confirms our former test and conclusion that the strips of paper are positively charged, for we know that the ebonite is charged with negative electricity. But this result would not be a conclusive proof by itself; for, as we shall presently observe (and as we have frequently observed before), attraction takes place

battery, which we agreed to call the *positive* pole; and that the electrification of *ebonite* rubbed with flannel is *identical* in kind with that obtained from the free *zinc* pole, which we agreed to call the *negative* pole of the battery.

between a body charged with either kind of electricity and an uncharged or neutral body, although not so strongly as between the same charged body and another one charged equally with the unlike kind of electricity.

Third, Bring forward the closed hand or any round conductor held in the hand towards the strips of paper. You observe that the strips are attracted thereby. The precise reason for this latter case of attraction will be explained when we come to treat of induction, but at present the circumstance is sufficient to cause us to warn the student *never to depend solely upon attraction* as a test of the kind of electricity with which a body may be charged.*

We shall now describe a very simple and useful apparatus for enabling us to detect whether a body is charged or not, and if electrified, whether the charge is positive or negative, viz. :—



GOLD-LEAF ELECTROSCOPE FOR LECTURE-TABLE.

D	represents	Disc (brass).
S	,,	Shellac plug.
R	,,	Rod (brass).
C	,,	Clip (brass).
L_1L_2	,,	Leaves (gold).
GJ	,,	Glass jar.
WB	,,	Wooden base.

The Gold-Leaf Electroscope.—Anything for showing the presence of an electric charge is termed an Electroscope, since the word is derived from the two Greek words ἤλεκτρον (*electron*), signifying amber, and σκοπός (*skopos*), to behold. The pith-ball pendulum, the balanced lath, glass and ebonite rods, and the suspended strips of paper used in the previous experiments, are all electroscopes. The first electroscope was devised by Dr. Gilbert about 1600 A.D. It consisted of a straight piece of light straw suspended upon a fine point; but for some of our experiments we require something far more delicate and certain of action than these things.

The above figure illustrates a simple form of gold-leaf electro-

* The student will remember that we cautioned him, when treating of tests for magnetisation and magnetic polarity (see Lecture IV., p. 29), never to depend solely upon attraction as a proof of a body being permanently magnetised, and we also stated that he *must always obtain repulsion* between one pole of his test needle and a pole of another magnet before he can be certain whether the pole of the magnet under test is a North or a South-seeking pole. It is precisely the same with electrical charges. The student *must* obtain some indication of repulsion between a charge of known kind and another charge before he arrives at a definite conclusion as to the kind of charge he is investigating.

scope, which, if made of sufficient size, will enable every member of a large class to observe simultaneously the results demonstrated on the lecture-table.*

As will be gathered from an inspection of the above figure and index to parts, the gold-leaf electroscope consists of a dry, clean glass jar, GJ, of spherical form, ending in a wide open neck, and supported by a wooden base, WB. Into this jar there is introduced a metal rod, R, ending in a flattened clip, C, or a hook, to which are gummed two gold leaves, L_1L_2, one to each side of the clip. These leaves hang down vertically and parallel to each other when in a neutral or uncharged condition, but diverge like the inverted letter Λ when a charge of positive or of negative electricity is given to them. A charge is imparted to the leaves either by direct contact between a charged body and the metal disc, D, or by induction between the body and the disc, which latter being screwed to the rod, R, is consequently in perfect metallic connection with the gold leaves. The disc, rod, and leaves are thoroughly insulated from the neck of the jar by a long double conical plug of pure shellac, tightly cemented between the wooden cork and the metal rod. If this cork be also well covered over with shellac, and cemented air-tight into the neck of the jar (after expelling any moisture from the jar by warming it gently before an open fire), then there will be no need whatever for introducing any moisture-absorbing devices† in order to obtain perfect insulation. If carefully made and used, this form of instrument will retain a charge for many hours without appreciable diminution; and even when it does show a tendency to leak after being unused for some time, if the outstanding cone of shellac be carefully scraped with a sharp knife or a piece of glass, the insulation will be restored.

Uses of the Gold-Leaf Electroscope.—We shall have occasion to make use of this instrument in the Elementary and Advanced Courses, for—

First, Detecting whether a body is charged with electricity.

Second, Ascertaining if a charge is positive or negative.

Third, Testing if a substance is a conductor or an insulator.

Fourth, Indicating the "*electric density*" or quantity of electricity per unit area of a charged surface.

Fifth, Determining roughly the potential difference (P.D.) between two charged bodies, or a charged body and the earth.

* See the Appendix to Part III. for how to make this form of lecture-table gold-leaf electroscope. Two large instruments of this form should always be on the lecture-table when demonstrating Frictional Electricity.

† Such as pumice-stone soaked in strong sulphuric acid, or pieces of calcium chloride.

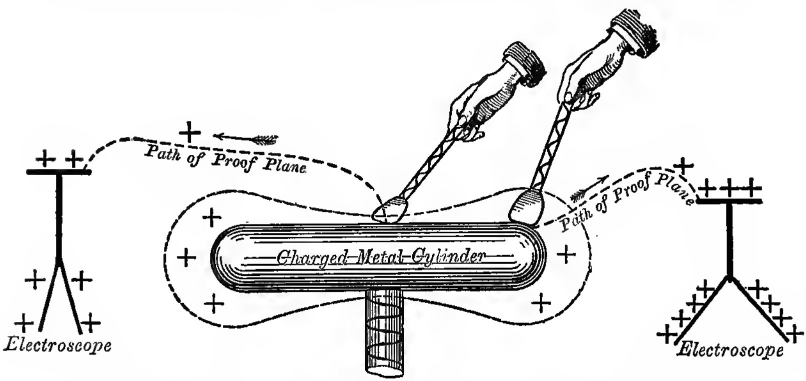
How to Detect by the Gold-Leaf Electroscope whether a Body is Charged.—We may adopt one or other of the three following methods, whichever may be most convenient at the time.

EXPERIMENTS IV.—(1.) *By direct contact between the body and the top disc or cap of the electroscope.**—Bring any *unrubbed* body into contact with the disc D, and if no divergence of the leaves be observed, then you are certain that the body is in an uncharged state.† Bring any of the rubbed rods that you have hitherto experimented with, or any insulated body, into contact with the cap, and if the leaves diverge ever so little, you conclude that the body is charged.

(2.) *By transfer, &c., aided by the proof-plane.*‡—Take a proof-

DIFFERENT FORMS OF PROOF-PLANES.

plane (which is simply a small metal disc or plate with rounded edges, or in some cases a small metal ball, fixed to a long insulating



DETECTING CHARGES BY PROOF-PLANE AND GOLD-LEAF ELECTROSCOPE.

handle of ebonite or of varnished glass), and bring the metal part of the plane into intimate contact with the body to be tested, so

* Great care must be observed, in adopting this method, not to bring the body too quickly forward to the cap of the electroscope; for should the body happen to be highly charged, the leaves may be so suddenly and widely extended that they become torn or broken away from the clip.

† It is absolutely necessary to have the electroscope in as perfect a condition as possible, so that false results may not be obtained, due to leakage from the electroscope to earth.

‡ See Appendix, how to make a proof-plane.

that the former may be charged to the same potential as the body (if a charge exists on the same). Then transfer the plane to the disc of the electroscope, in the manner shown by the previous illustration, without letting it touch any other body. If the leaves diverge, then the body was charged; if not, it was in a neutral condition.*

(3.) *By induction.*—Electro-static induction and its actions will be more fully explained in a following lecture, but at present it will be sufficient to inform the student that if he brings any body gradually near to and fairly over the cap of an uncharged electroscope, and observes while doing so that the leaves gradually diverge, then he may conclude that the body is charged. This is the simplest and quickest way of detecting whether a body is charged. It has the further advantage of not abstracting any portion of the charge from a charged body, and of leaving the electroscope neutral after the removal of the body.

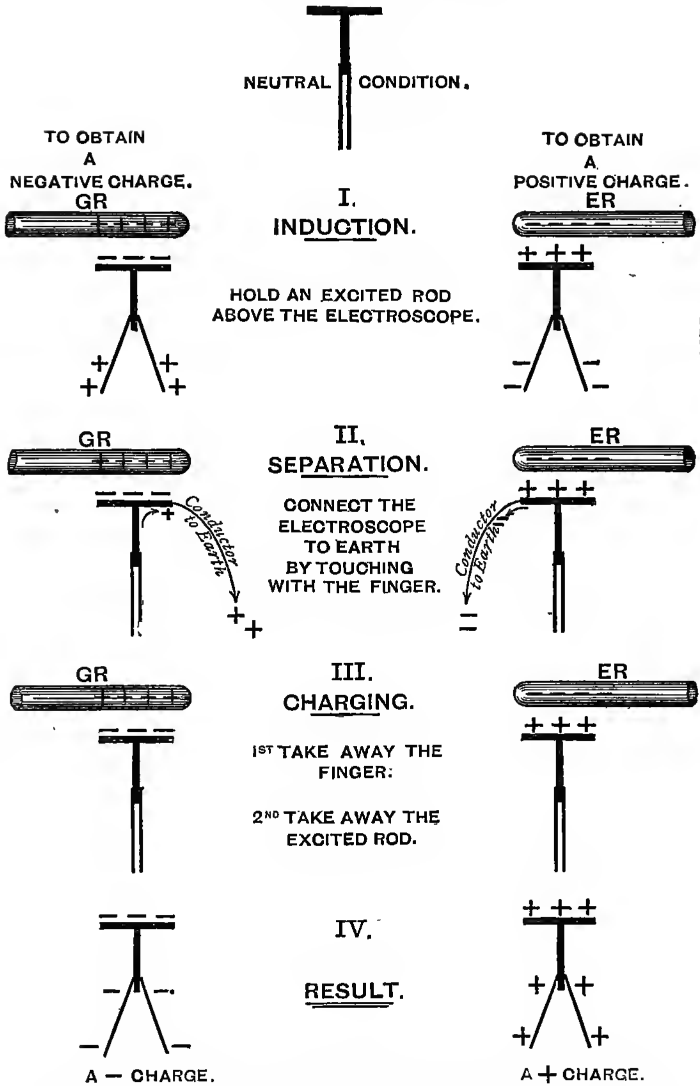
How to Ascertain by the Gold-Leaf Electroscope whether a Body is Charged Positively or Negatively.—

First, Charge one electroscope positively and another negatively.† The one electroscope may be *positively* charged by direct contact from a glass rod rubbed with amalgamated silk, or by aid of a proof-plane as explained in Experiments IV., while the other may be charged *negatively* in a similar manner from an ebonite rod rubbed with flannel. A more effective plan, and one which will be better understood by the student when he has mastered induction, is fully illustrated by the following full-page set of figures and instructions.

Second, Bring the body whose charge you wish to test fairly above and gradually near to the cap of the *positively*-charged electroscope. If you observe a greater divergence of the leaves, then the body is *positively* charged. If the divergence of the leaves diminishes as you bring the body forward, then bring it over the cap of the *negatively* charged electroscope, and should

* The student will observe that we have drawn a wave-line along the handles of the several proof-planes, as well as along the support to the charged metal cylinder in the above figures. This is a convenient method of indicating that rod, handle, or support is an insulator, and we shall consequently adopt it throughout this part of the Manual. He will also observe that we have dispensed with the glass jar and base of the electroscope, and have only used the conventional method of indicating this instrument by the simple skeleton figure . In the written answers to questions we will accept from students these signs without the words "insulator" or "electroscope" being written near them, where the signs can be conveniently adopted by themselves.

† To demonstrate this experiment quickly and effectively before a large class, it is better to use two electroscopes placed a few feet apart on the lecture-table, so that the students may the more easily observe the different effects simultaneously, or with as little delay as possible.



How to Charge a Gold-Leaf Electroscope Negatively or Positively by Induction and Separation.

you now obtain greater divergence of its leaves, the body is *negatively* electrified. Should you, however, get diminished divergence of the leaves of both electroscopes, then the body is a conductor and is either *neutral* or *earth-connected*.

Third, Conversely, you may test whether an electroscope is *positively* or *negatively* charged by bringing over it in turn a glass rod rubbed with amalgamated silk, and an ebonite rod rubbed with flannel. If the approach of the glass rod produces *greater* divergence, then the electroscope is *positively* charged, but if the approach of the *ebonite* rod produces *greater* divergence, then the electroscope is *negatively* charged.

Caution.—*Never depend upon convergence of the leaves as a test of the kind of electricity with which anything may be charged.*

LECTURE XXII.—QUESTIONS.

1. Explain in your own words what you understand by the terms "positive" and "negative" electrifications, and state the law of Attraction and Repulsion.

2. How would you prove to a class that there are two kinds of electricity? (S. and A. Exam., 1888.)

3. A sheet of hot brown paper is placed on a board and india-rubber is passed briskly over it. Two strips are cut from the paper, and held up close and parallel to each other. How will they act upon each other? A glass rod rubbed with silk repels both the strips; what is the inference? (S. and A. Exam., 1876.)

4. You are required to give an experimental proof of the law that bodies oppositely electrified attract each other, and bodies similarly electrified repel each other. Tell me the substances you would choose, and the manner in which you would use them to obtain the desired result. (S. and A. Exam., 1877.)

5. A strip of paper rubbed with india-rubber is brought near to a glass rod which has been rubbed with silk; what follows? Deduce from this experiment the quality of the electricity on the paper.

6. If you want to find out whether a body is electrified by seeing how it acts on an electrified pith-ball hung by a silk thread, why is it a surer test that the body is electrified if it repels the pith-ball than if it attracts it? (S. and A. Exam., 1881.)

7. Supposing you were required to test the quality of the electricity with which an insulator is charged, how would you do it? (S. and A. Exam., 1878.)

8. A certain substance becomes electrified when it is rubbed with a silk handkerchief. How would you determine whether its electrification is positive or negative? (S. and A. Exam., 1889.)

9. When a piece of sealing-wax and a piece of dry flannel are rubbed together, one becomes positively electrified and the other negatively electrified. When a piece of brown paper and a piece of india-rubber are rubbed together, one becomes positively electrified and the other negatively electrified. How could you find out which of the four things, sealing-wax, flannel, paper, india-rubber, are in the same electrical state? (S. and A. Exam., 1882.)

10. An insulated conductor, A, is brought near to the cap of a gold-leaf electroscope which has been charged positively. State and explain what will happen: (1) if A is unelectrified; (2) if it is charged positively; (3) if it is charged negatively. (S. and A. Exam., 1887.)

11. Two copper wires, connected, one with the zinc end and the other with the platinum end of a voltaic battery, but not connected with each other, are brought near a piece of sealing-wax that has been rubbed with flannel and then nicely balanced on a point. Would the wires differ in any way in their action upon the sealing-wax? If so, how? and why? (S. and A. Exam., 1882.)

12. An insulated positively-electrified gold-leaf hangs half-way between two vertical insulated and unelectrified copper plates, A and B, to each of which a copper wire is attached. If plates of zinc and copper, which are partly immersed in dilute acid, are touched by the wires attached to A and B respectively, and if afterwards the wires are both dipped into the acid, describe the movements of the gold-leaf in each case. (S. and A. Exam., 1888.)

13. Sketch and describe by an index to parts the common gold-leaf electroscope. Explain how you would use it to ascertain whether a charge is positive or negative. Why is repulsion the only sure test of electrification?

14. Given a positively charged body, explain how you could charge an electroscope by it with either positive or negative electricity. (S. and A. Exam., 1891.)

LECTURE XXIII.

Conductors and Insulators.—The student who has read **Part II.**, and who has witnessed lecture or laboratory experiments with currents derived from ordinary batteries and dynamos, will have to modify his ideas somewhat in regard to what constitutes a reliable insulator when he deals with statical electricity experiments. For example, he has noticed that a base or support made of ordinary wood was a sufficiently good insulator to prevent any appreciable leakage of current from a terminal wire or an instrument when the electrical pressure did not exceed say 100 volts. Such a base would be utterly useless to restrain a charge derived from a rubbed glass or ebonite rod where the E.M.F. perhaps exceeds 10,000 volts. When he comes to consider frictional or influence machines giving pressures of 50,000 to 100,000 volts (which cause sparks to pass through several inches of dry air), then he will find he is still further restricted in his choice of insulators. In the case of lightning discharges there is no known substance that will insulate them should they be obstructed in their path, for with them the voltage may attain to millions of volts. Electricity generated by any means is always electricity—*nothing else*—just as heat, however caused, is always heat. The behaviour and the effects on matter of low and high pressure electricity perhaps vary quite as much as do the effects of low and high temperatures of heat; consequently you will observe that we are now dealing with another phase of this mysterious force. Engineers who were accustomed to low-pressure steam, water, and air results, had to alter their practice and modify their materials and engines when they came to introduce the high pressures now common in the employment of such stores of potential energy. In the same way electricians and physicists

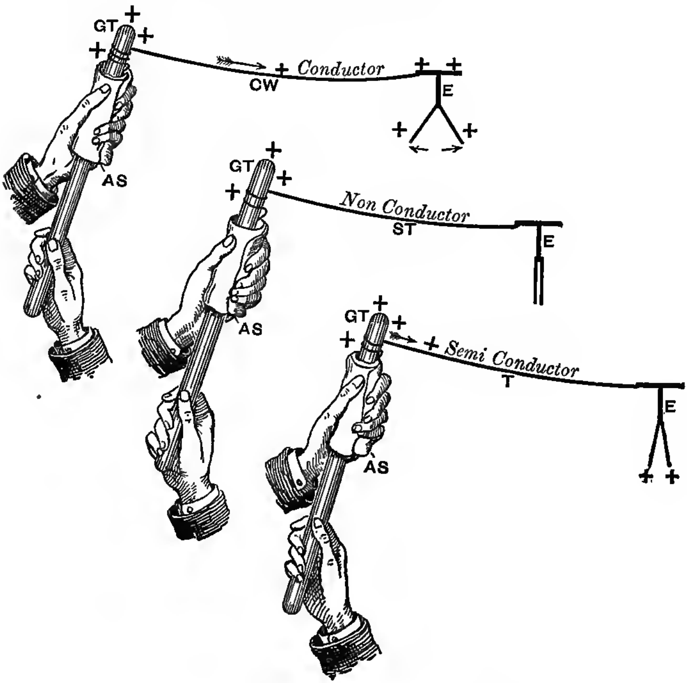
have to use other materials and other forms of apparatus when they experiment with, or apply for any useful purpose, electricity of the potential we are now considering.*

With these few preliminary remarks we shall now proceed to show how you can test whether a substance is a conductor or an insulator of high-pressure electricity by means of the gold-leaf electroscope, and then state a few definitions which naturally result from the effects observed.

How to Test by the Gold-Leaf Electroscope whether a Substance is a Conductor or an Insulator.—EXPERIMENTS V.—(1.) Suppose we select certain substances, such as ten or twelve feet of copper wire, silk thread or ribbon, and ordinary hempen twine. Connect in turn one end of each to a small hole in the cap or disc of the gold-leaf electroscope and twist the other end loosely round a dry glass tube or an ebonite rod. Rub the glass tube, GT, as previously directed (and illustrated on p. 222), with an amalgamated silk rubber, AS. Now observe the different effects upon the electroscope leaves as you let the twisted part slide down over the rubbed end of the tube after removing the rubber. In the case of the copper wire, CW, you find that the leaves diverge instantly and very wide apart, thus indicating that a charge has passed from the glass through or along the surface of the wire to the electroscope, and proving that copper is a conductor. With the silk thread, ST, no divergence of the leaves is found to take place, and you conclude that silk is a good insulator. Damp this thread ever so little with a sponge or the moistened hand *from end to end*, and again rub the tube and let the twisted part slide down it slowly towards the hand. The leaves diverge, but not so quickly as in the case of the copper wire. If the thread be now allowed to come into contact with the left hand, or if it be grasped with the other one, the electroscope is discharged, because the charge on the electroscope now passes to earth through the damped thread and the body of the operator. These two last results show that water, or even a film of moisture, serves to conduct the high-pressure electricity, and warn you that no charge can be retained for long on any body connected with another body or with the earth by the faintest trace of a damp path. Lastly, test the dry twine, T, in the same

* This very subject of insulators and insulation is at present receiving the closest attention and trying the best efforts of the most skilled electricians in the case of the attempt to supply the City of London from Deptford with an alternating current of 10,000 volts pressure for purposes of electric lighting, &c. It is found very difficult to insulate electricity of this pressure under the particular circumstances of having to transmit the energy by underground conductors, and as yet (September 1890) the problem has not been satisfactorily solved

way, and you see that the leaves diverge very slowly but surely, and discharge as slowly should you connect the hand-end of the twine with earth; from which indications you put dry hempen twine amongst imperfect or semi-conductors.



TESTING BY THE GOLD-LEAF ELECTROSCOPE WHETHER CERTAIN SUBSTANCES ARE CONDUCTORS OR INSULATORS.

(2.) Should the substance you wish to test not be in the form of a cord or string, or should it be one which you cannot in any convenient way connect between an excited rod and your electroscope, then the simplest way of testing its qualities and condition is to charge the electroscope with positive or negative electricity, and, holding one end of the substance in your hand, bring the other end or part you wish to test into contact with the metal cap of the electroscope. Should the leaves not diminish in divergence in the slightest degree after holding the body in this position for a minute or so, then you are entitled to conclude

that it is a good insulator.* For example, take a brass tube, and, holding it in the hand at or by *any* part (either end or the middle), touch the cap of a charged electroscope with any other part of the tube, and *instantly* the whole charge is conducted to earth. The result will be precisely the same if any other metal or conductor be applied to the electroscope in the same way. Now fix a clean dry glass rod into the open end of the tube, and holding the other end of the glass rod in the hand, touch the charged electroscope with any part of the brass tube; the leaves will slightly diminish in divergence, owing to part of the charge on the disc and leaves now spreading over an enlarged area, viz., the whole of the tube; but if the glass be good, the leaves will remain steady at the first diminished divergence. Take the brass tube in the hand and touch the charged electroscope with *any* part of the clean dry glass rod; not the slightest diminution of divergence is observable, since the electricity cannot pass along the surface or through the body of the rod, due to the great insulation resistance of the glass. Breathe upon the surface of

ELECTRIFICATION OF A CONDUCTING BODY, AND TESTING THE CHARGE AS WELL AS THE INSULATION OF THE SUPPORT OR INSULATING HANDLE.

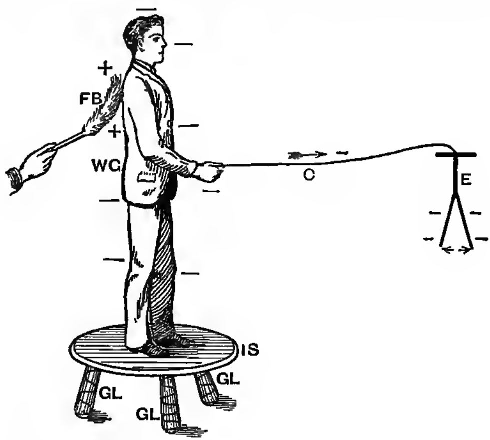
the glass, or draw however narrow a streak along it with a dirty cloth or piece of wood, and again apply it to the charged electroscope. The difference from the previous result is at once observable by the leaves coming together more or less quickly, according to the quantity of moisture or conducting film on the surface of the glass.

Electrification of Conductors by Rubbing.—EXPERIMENTS VI.—(1.) *Electrification of a brass tube.*—If you hold a brass tube (or any insulated conductor) in the hand, and flip it with a cat's skin or fox's brush, and then touch the cap of the electroscope with the brass, no sign of electrification is observable. Support it by the clean dry glass handle, and again flip the brass

* CAUTION.—*Immediately* before demonstrating *any* experiment on frictional electricity to a class, the lecturer should *always* test the insulation of the apparatus he is to use by this simple method. If he neglects to do so, he will be certain to fail some time or other. His assistant should also have tested everything before the class meets (more especially insulating supports and stands), and have rejected or put them into perfect order. There is nothing more annoying than the slow creeping away of a charge before one's eyes, due to a film of dirt or moisture, when explaining what a result should be, but which result does not take place, owing to want of attention to this simple precaution.

tube with the fur or brush; on touching the electroscope with *any* part of the metal, electrification is at once exhibited by great divergence of the leaves.

(2.) *Electrification of the electroscope by a camel-hair brush.*—Stroke the disc of the electroscope with a camel-hair brush for a number of times, and at each stroke of the brush the leaves diverge further and further. Test the charge, and it will be found to be negative. This shows that conductors have *only* to be properly insulated, and excited in a suitable manner, in order



ELECTRIFICATION OF THE HUMAN BODY BY A FOX'S BRUSH.

E	represents	Electroscope.
C	„	Conductor.
WC	„	Woollen coat (−).
FB	„	Fox's brush (+).
IS	„	Insulating stool.
GL	„	Glass legs.

that they may show signs of electrification. This electric charge, however, spreads over the whole of the conductor in a manner that will be explained when we come to discuss the subject of "Distribution of Charges on Conductors."

(3.) *Electrification of the human body.*—Get an assistant or student to stand upon a well-insulated stool, and to hold a conducting wire connected with a gold-leaf electroscope.* Stroke him down (as shown by the accompanying illustration) with a fox's brush, or hit him with a cat's skin or other fur. After a few strokes of the fur the leaves of the electroscope will

* The experiment will succeed best if the person standing on the stool is provided with a dry woollen coat.

begin to diverge, and then each successive stroke will cause increased divergence. If the conducting wire connecting the insulated person's hand and the cap of the electroscope be now removed by an insulating handle or tongs (see illustration p. 238), then, upon testing the charge remaining on the electroscope, it will be found to be negative. Should the person simply stand on the insulating stool, and be unconnected with any other thing, then after flipping his coat for a short time, electric sparks may be drawn from his nose or any part of his body by some earth-connected person presenting his knuckle to the part. On presenting an open hand over his hair, if the hair be long, fine, clean, and dry, it will stand on end!

On a very frosty day, if a person skip or slide over a thick fur rug or soft thick woollen carpet, he will become so charged with electricity that, upon presenting his knuckle to any earthed connection, a visible spark will pass between him and earth. It has been reported to the author by a person who was residing in the dry atmosphere of Canada, that during frosty weather he could light the gas by this means, upon simply presenting his knuckle fair above and near to the gas-burner when the gas tap was turned on!

Before giving the following definitions regarding conductors and insulators, we would advise the student to refer to the list of conductors and insulators which is printed in Part II., page 174. All the conductors, fair conductors and semi-conductors, down to and including "flame," may be considered good conductors, as far as high-pressure statical electricity of 10,000 or so volts is concerned. From "linen" down to and including "porcelain" may be considered semi-conductors; and from silk to the end insulators up to 100,000 or so volts. When we reach that pressure and over, the electricity can only be kept within bounds by the very best glass, ebonite, and shellac, so formed as to present a surface of great length, and consequently high resistance. Should reaction due to oscillatory pulsation set in by a leak or starting of a current, it will either pierce directly through the glass, shiver it to pieces, or jump over spaces of many inches in length, in order to reach an oppositely-charged body or the earth, as has been shown so graphically by Dr. Lodge's recent investigations and experiments on lightning and lightning conductors.

Definitions.*—*Conductor.*—If one portion of an isolated† body has electric charge imparted to it, and it is found that in a very small fraction of a second

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* These definitions, as we have stated them, were drawn up by Professor Fleming, convener of the Nomenclature and Notation Committee appointed by the Institution of Electrical Engineers.

† An isolated body is an insulated body removed far from other bodies.

the electrification distributes itself over the body in a perfectly definite manner (depending upon its shape and its relation as to position with regard to surrounding bodies), then that substance is called a *conductor* of electricity or a conducting body.

Insulator.—If electric charge can be imparted to, or caused to appear on, *part* of a body in any arbitrary manner, and does not tend very quickly to assume a definite distribution, then that body is called non-conducting, and is an *insulator.*

Imperfect Conductors.—There is no naturally marked boundary between conductors and non-conductors. All insulators conduct to some small extent, and all conductors offer some degree of *resistance* to the spread of electric charge over or through them. There is a large class of bodies to which the terms conductor and non-conductor can only be applied relatively, and these are called *imperfect conductors* or imperfect insulators; such as wood, paper, leather, for example.*

Conduction is a term applied to the process by which electrification is transferred from place to place on one body, or from one body to another.

Insulation is a term applied to the state of a body indicating that its electrification is permanent, or very nearly so, and that electric charge is not passing to or from the body to any measurable extent.

Convection.—When electric charge is removed from or given to a body by means of the continual contact and motion of small bodies, such as particles of dust, which particles act as vehicles to carry electric charge from one place to another, this is called *electric convection.*

Creeping.†—When electric charge passes over the surface of an insulating body, not in virtue of conduction by the body itself, but in consequence of a film of dirt or moisture which does conduct, this process of losing charge is called *loss by creeping.*

Conductivity.—That quality of a body in virtue of which it permits the distribution of electric charge over it or through it is called its *conductivity.* The reciprocal quality is called *electric resistance.*

The student should consider these definitions most carefully in the light of the foregoing experiments, and of any others which his teacher may think advisable to show him.

Specimen Question and Answer.

Question.—Two pith-balls, suspended, one by a damp cotton thread, the other by a dry silk thread, are each of them touched by a positively-charged glass rod. Will there be any difference between the behaviour of the two balls? If so, what difference? and why?

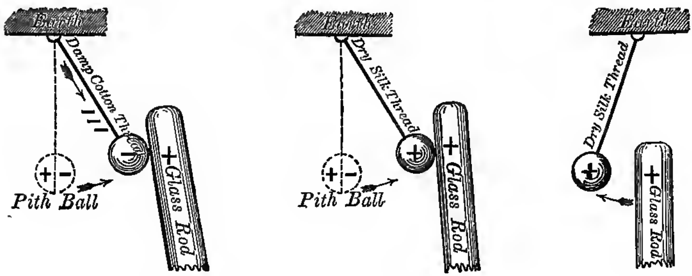
Answer.—Yes. The *difference* will be that the pith-ball suspended by the *cotton thread* will *adhere* to the rod, but will shift

* As we said in the text, it depends partly on the condition of the surface of these bodies and partly upon the electric pressure brought to bear upon them whether the bodies should be classed as conductors or insulators.

† Given good materials and apparatus to begin with, it is this action which he demonstrator has most to contend with. See Appendix as to how to prevent it in the case of glass and ebonite stands and insulating handles or supports.

its position over the surface until the rod is discharged; whereas the pith-ball suspended by the *silk thread* will be *repelled* the instant it touches the rod, and remain repelled so long as it keeps the charge received during the first contact. Should the ball lose its charge, it will be again attracted and remain repelled for a considerable time, and so on.

The *reasons* for the difference are explained by the three following sketches and accompanying remarks :—



The + on the rod attracts – from earth slowly through the semi-conducting cotton thread and pith-ball. When this – has cancelled the + on rod at any spot, the ball is attracted by induction to a fresh place, and so on until the rod is discharged; for the rod being an insulator, it cannot part with its charge except by contact with each point.

The + charge on the rod repels the + charge left on the ball. The ball's charge, however, disappears *very* slowly by leakage through the insulating silk thread; after which the ball is again attracted by induction to the glass rod.

Lecture XXIII.—Questions.

1. Why are some bodies considered insulators for low-pressure electricity and conductors of high-pressure electricity?

2. Two strings are given to you, and you are required to test whether they insulate or conduct electricity; how will you do it? (S. and A. Exam., 1873.)

3. You have several rods of unknown materials. Describe exactly (with the aid of neat sketches) experiments which would enable you to distinguish those of them which are conductors of electricity from those which are non-conductors. (S. and A. Exam., 1880.)

4. A stick of sealing-wax held in the hand and rubbed with dry flannel is found to become electrified. A brass rod after being treated in the same way shows no electrification. How do you account for the difference? (S. and A. Exam., 1886.)

5. Arrange the following substances in the order of their conductivity for electricity, putting the name of the best conductor first: air, copper, glass, iron, sea-water, shellac, water (pure), wood. (S. and A. Exam., 1882.)

6. A piece of brass tube held in the hand and struck with a cat's skin shows no electricity when it is made to touch an electroscope. How would you prove experimentally that it was really electrified when so struck? (S. and A. Exam., 1883.)

7. How would you prove that an iron poker struck with fur was electrified? How would you find out the kind of its electrification?

8. An apple held in the hand and struck with a fox's brush shows no signs of electrical action; suspended by a string of silk and struck with the brush it becomes electrified, attracting light bodies, and causing the leaves of the electroscope to diverge. Explain these results. (S. and A. Exam., 1876.)

9. A pith-ball is suspended from a metal stand by a fine thread. If you have a strongly electrified glass rod, how can you find out whether the thread is a conductor or a non-conductor of electricity? (S. and A. Exam., 1887.)

10. Two pith-balls hang side by side by two damp cotton threads, and another pair by dry silk threads. State and explain what happens when an excited glass rod is brought gradually near each pair of balls from below.

11. Two pith-balls, suspended, one by a damp cotton thread, the other by a dry silken thread, are each of them touched by the knob of a charged Leyden jar, which is held in the hand by its outer coating. Will there be any difference between the behaviour of the two balls? If so, what difference? and why? (S. and A. Exam., 1885.) *Consider the Leyden jar as a charged conductor.*

12. Define conductor, insulator, conduction, insulation, creeping, and conductivity, in your own words.

13. What is meant by the terms "conduction" and "insulation" as applied to frictional electricity? Describe an experiment which shall illustrate the properties of metal wire, common twine, and a silk string, as regards conduction and insulation. (S. and A. Exam., 1876.)

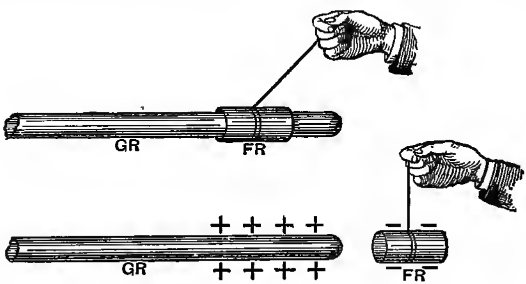
14. A brass rod, after it has been insulated and rubbed with a piece of silk, is placed on the plate of a gold-leaf electroscope. The leaves diverge. The divergence increases when a warm glass rod, rubbed with sealskin, is brought near to the electroscope. What inference can be drawn as to the sign of the electrification of the brass? (S. and A. Exam., 1891.)

LECTURE XXIV.

CONTENTS.—Simultaneous and Equal Generation of Positive and Negative Electricity—Analogy between Pneumatic and Electric Generation of Positive and Negative Pressure and Quantity—The Frictional Series—Other Ways of Developing Electricity, such as Cleavage, Pressure, Change of Temperature, Evaporation of Water and Condensation of Steam in Motion—Questions.

Simultaneous and Equal Generation of Positive and Negative Electricity.—In the description of our frictional electricity experiments we have hitherto only considered the electrical condition of the bodies rubbed. We shall now investigate the state of the rubber.

EXPERIMENT VII.—(I.) Take a glass rod, GR, and a frictional rubber, FR, of amalgamated silk. Attach a silk string firmly to



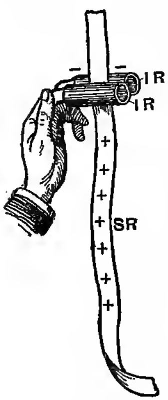
SIMULTANEOUS AND EQUAL GENERATION OF POSITIVE AND NEGATIVE ELECTRICITY.

the rubber, and push the latter on to the rod, as shown by the first of the two following figures. Holding the string taut by one hand, turn the rod round by the other hand a few times, and then pull the rubber smartly away from the rod.* Test by aid of the gold-leaf electroscope the charges generated on the glass rod and on the silk rubber. You find that the charge on the rod is

* You may hold the rod firm with the cap on it and twist the string round the cap. On pulling the string, the cap will spin rapidly round the rod and then be drawn away from it.

positive, and that on the rubber *negative*. Now completely discharge the rod, rubber, and electroscope. Replace the rubber on the rod, and turn the latter round several times inside the rubber as before, but without removing it from the rod, and place both together on the cap of the electroscope. No sign of electrification is observable. This proves that the + charge on the rod exactly balances the equal and − charge on the rubber.*

If after separating the rod and rubber by pulling the insulating silk string, you could transfer the whole of the + electricity from the glass rod to the electroscope quickly, and then place the rubber on the cap before any of its − electricity had leaked away, you would find that the electroscope would be rendered neutral by the combining of the equal + and − charges. Or, if you could charge the electroscope with the *whole* of the + electricity from the rod and watch the precise divergence of the leaves, then, after discharging the electroscope, again charge it with the *whole* of the − electricity from the rubber, you would obtain the same divergence of the leaves. It is, however, practically impossible to perform these two suggested experiments satisfactorily before a class, due to the difficulty of removing the *whole* of the charge from the glass rod, owing to its insulating properties, whereby the charge remains fixed; and further, owing to the time which must necessarily elapse in attempting to remove the charge from the rod by any form of proof-plane, which gives a chance of a part of the charge on the rubber leaking to earth by the silk string and hand. If you, however, take the insulated brass tube (illustrated at page 223) and rub it with, say, a flannel rubber, insulated by a silk string (as in the previous experiment), or wrap the flannel round an insulated rod and then rub the tube with it, the charge generated on the brass tube may be made to cancel the whole charge on the rubber by laying the rubber on the cap of the electroscope and then placing the charged brass tube on the top of it.



SILK RIBBON RUBBED WITH INDIA-RUBBER.

* After the separation of the rod and its rubber the electric energy stored on them is merely the equivalent of the very small amount of work spent in separating the two against the attractive force of the + electricity on the rod for the − on the rubber. This energy is not in any way a definite fraction of the work that was spent in rubbing the rod; but, as we shall have reason to observe afterwards, the heat generated by the discharge between the electricity of the rubber and the body rubbed is a direct and accurate measure of the work done in separating them.

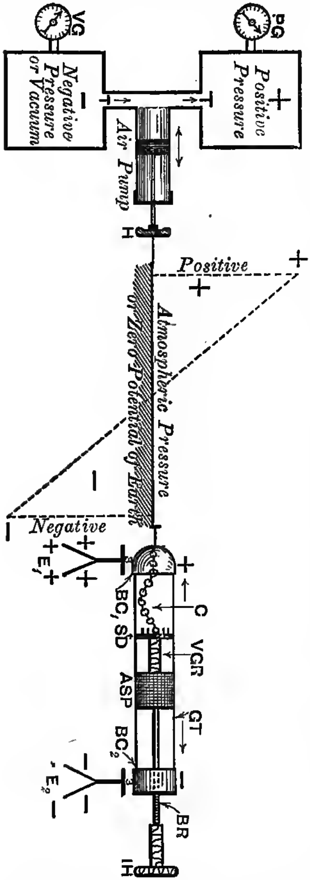
You may vary the above experiments in many ways. For example, you may take a rod of resin, sealing-wax, or ebonite with an insulated flannel or fur rubber, or a silk ribbon, SR, rubbed by two india-rubber tubes, as shown by the accompanying illustration, and on testing the results by the gold-leaf electroscope, you find that equal quantities of positive and negative electricity have been simultaneously generated on the rubber and the body rubbed.

Analogy between Pneumatic and Electric Generation of Positive and Negative Pressure and Quantity.—Attempts have been made to draw an analogy between chemical separation and combination in order to help the understanding of the equal development of positive and negative electricity, but they are not conclusive. A closer similarity may be shown between this electrical phenomenon and the mechanical one by aid of the following experiments and diagrams (see next page).

The central figure of the following illustration serves to show graphically by a geometrical representation the equal positive and negative pressure and quantity developed by the pneumatic mechanism above and below atmospheric pressure, and by the electric mechanism above and below the earth's potential taken as zero. As in geodesy or surveying, it is found convenient to consider the level of the sea as *zero level*, and to measure from this datum-line the heights of mountains *above* it, the depths of the sea or of mines *below* it; so, in like manner, we take the potential of the earth's surface as *zero potential*, using the same as a suitable and invariable point of reference from which to measure positive or high potential above it, negative or low potential below it.

The Frictional Series.—The kind of electrification generated on a body is not always the same. For example, glass rubbed with silk becomes (as we have frequently observed) positively electrified; but rub the glass with flannel or with fur, and it becomes negatively electrified. A difference merely in the surfaces of two bodies of the same substance, whether of structure or temperature, is sufficient to cause opposite electrification when they are brought into contact or rubbed together, as may be found by rubbing a piece of smooth glass over etched or ground rough glass. The smooth glass becomes + to the same extent as the rough glass becomes −. A piece of cold glass becomes + to a piece of warm glass when they are rubbed together, and generally when two pieces of the same substance are rubbed together, the smoother and the colder becomes positively electrified. Professor Forbes in his "Elementary Lectures on Electricity," delivered

before the Society of Arts, remarked, "We find that the surface has an influence on the character of the electrification. Thus



PNEUMATIC MECHANISM, GEOMETRICAL FIGURE, AND ELECTRIC SYRINGE TO ILLUSTRATE THE ANALOGY BETWEEN THE SIMULTANEOUS AND EQUAL GENERATION OF POSITIVE AND NEGATIVE PRESSURE AND QUANTITY.

EXPERIMENTS VIII.

(1.) Take the simple pneumatic mechanism illustrated by the upper or top figure, consisting of two vessels of equal capacity, containing air at atmospheric pressure, and connected by a short pipe with suitable valves. To the middle of this pipe fix an air-pump. Now work the handle, H, of the air-pump to and fro, and thereby extract air from the lower, and at the same time force this air into the upper one. The vessel into which the air is forced thus increases in pressure and in quantity (or becomes *positive*) in an *equal degree above* the normal atmospheric pressure and quantity per unit volume to that in which the lower one decreases in pressure and in quantity (or becomes *negative*) below the atmosphere. The *positive* and *negative* pressures may be indicated by pressure and vacuum gauges, PG and VG, *and their sum is always constant.*

(2.) Take an electric syringe, as illustrated by the lower or bottom figure, consisting of a glass tube, GT, fitted with an amalgamated silk piston, ASP, connected on the one side by a brass rod, BR (passing through a brsss cap, BC_2), to an insulating handle, IH, and insulated on the other side from a spiked disc, SD, by a varnished glass rod, VGR. The spiked disc is connected to the end brass cap, BC_1, by a chain, C, or flexible conductor. Now work the insulating handle, IH, of the syringe to and fro, and thereby generate *positive* electricity on the inside of the glsss tube, and *negative* electricity on the amalgamated silk rubber. The positive electricity is collected by the spiked disc, and passing along the chain, charges the brass cap, BC_1, *positively.* The negative electricity on the rubber passes along the brass rod and charges the brass cap, BC_2, *negatively.* The positive and negative charges may be indicated by connecting BC_1 and BC_2 to two electroscopes or electric gauges, E_1 and E_2, *and they are always equal.*

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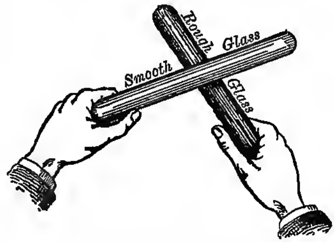
we find that a black ribbon rubbed on a white one is negative to it. We find that a hot piece of cork rubbed against a cold

one is negative to it. In all these cases of surface influence the best radiator of heat or light is the most negative. A hot body radiates more heat than a cold one, and is negative to it. A rough surface radiates more than a smooth one, and is negative to it. A black body radiates more heat than a white one, and is negative to it. I give this only as an aid to memory. I do not imply that there is a physical connection between the two phenomena, although there are some startling similarities in some of the actions of bodies in relation to heat and electricity."



LIKE SUBSTANCES WITH DIFFERENT CONDITIONS OF SURFACE WHEN RUBBED PRODUCE + AND – ELECTRICITY.

These and other circumstances, such as slight chemical differences, alter the position of a substance in any series that may be given, but the following order may be taken to represent roughly that the substances higher in the list become + when rubbed at normal temperature with any of those following, which become –.

(+).

1. Furs.	8. Glass (rough).	15. India-rubber (vulcanised).
2. Flannel.	9. Metals.	16. Gutta-percha.
3. Ivory.	10. India-rubber (pure).	17. Collodion.
4. Paper.	11. Ebonite.	18. Amalgamated surfaces.
5. Glass (smooth).	12. Sealing-wax.	
6. Cotton.	13. Resin.	
7. Silk.	14. Sulphur.	

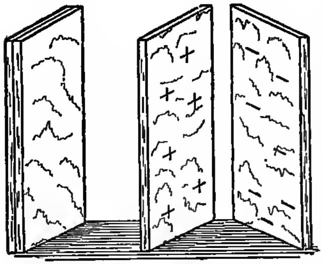
( )

Other Ways of Developing Electricity.—Besides friction, there are other ways of producing electrification, such as cleavage, pressure, change of temperature, evaporation of water, and condensation of steam with motion. In fact, any disturbance of the natural molecular condition of bodies produces electricity; and if the circumstances are favourable, such as the necessary insulation of one or both of the parts, the electrification may be observed and tested by an electroscope or electrometer.

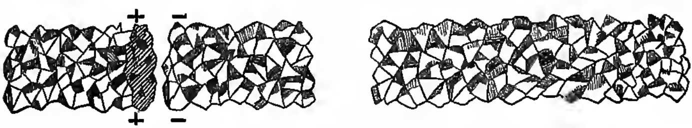
EXPERIMENTS IX.—(1.) *Cleavage.*—Take a slip of plate mica and quickly separate it into two parts, as shown by the accompanying figure; the one face of the cleavage will be found to be + and the other –. Break a piece of sugar-candy or loaf-sugar, or roll sulphur, and one face of the break will be found + and the other –. If these experiments are conducted in the

dark and in dry weather, they are accompanied by a slight luminosity of short duration.

(2.) *Pressure.*—If two insulators of different materials be simply pressed hard together and then separated, the parts which were in contact will be oppositely electrified. If calc-spar be pressed between the hands or finger and thumb, it becomes positively electrified. Many other minerals, such as fluor-spar, mica, and quartz, exhibit the same result when pressure is applied to them. Paper and cloth, as they are being wound from the hot-press rolls in the factory, often exhibit such a high degree of electrification that sparks of several inches in length may be got from them by simply holding the knuckle of the hand towards them. This phenomenon may be due to a combination of friction and pressure. In any case, it is a striking example of electrification, and often causes great trouble to the manufacturer by the paper or cloth adhering so firmly to the rolls that special arrangements have to be made in order to discharge the electricity to earth. In dry frosty weather you may obtain sparks several inches in length from the leather driving belt of a steam-engine, dynamo, or factory pulley.*



ELECTRIFICATION OF MICA BY CLEAVAGE.



ELECTRIFICATION OF SUGAR-CANDY BY CLEAVAGE.

* A favourite method adopted by young electrical engineers employed on electric light installations, for astonishing an uninitiated unsuspecting visitor and making him believe that everything connected with the premises is surcharged by electricity, is that of taking an ordinary beer-bottle half full of water, with a wire protruding from the neck of the bottle, and holding the bottle in the hand so that the wire is near the moving belt; the extemporised Leyden jar is thus charged with high-pressure electricity. The bottle is then brought near the hand, nose, or ear of the visitor until a discharge takes place through him, to his discomfort and amazement. The complete action of this experiment will be fully understood by the student when he has read the lecture on Leyden jars. The electricity thus obtained has, however, no connection with the electricity being specially generated by the dynamo.

(3.) *Change of temperature.*—Certain crystals of a non-conducting nature, such as sugar, topaz, boracite and tourmaline, acquire electrical polarity (+ at one end of an axis and − at the other) during heating, and the opposite polarity during cooling, between certain temperatures. The electricity thus generated has been termed *pyro*-electricity, and must not be confounded with *thermo*-electricity obtained by the heating of a contact junction of unlike metals, such as bismuth and antimony, used in the case of thermo-piles.

(4.) *Evaporation.*—"Pure water does not show any signs of electrification when evaporated; but if it contains free oxides of potassium, sodium, calcium, or barium, the water becomes + during its evaporation, whilst the vapour becomes − charged. If the water should, however, contain any soluble acid, carbonate, sulphate, chloride, nitrate, or acetate, the water becomes − and the vapour +." "When water is evaporated under pressure greater than one atmosphere, the quantity of electricity developed increases with the pressure, but in no case does it appear unless the water contains some of the above salts in solution." *

(5.) *Condensation in motion.*—The friction between partially condensed steam and the constricted nozzles through which it is escaping from an insulated boiler, electrifies the steam positively and the boiler negatively. Moist air driven through nozzles acts in the same way. It is conjectured by some that the combined effects of evaporation from the sea, subsequent condensation of the moisture into clouds, with differences of temperature and motion of the condensed aqueous vapour under the action of wind, produce atmospheric electricity kuown in its discharge as lightning.

Not one of these last five methods of generating electricity has been put to any useful purpose so far as we are aware, but there can be no doubt that the direct transformation of heat-energy into electric-energy will in the near future become one of the most efficient means of generating electricity.

* We are indebted for the above quotation to Professor Guthrie's treatise on Magnetism and Electricity.

Lecture XXIV.—Questions.

1. When you rub a stick of sealing-wax with flannel, what is the state of the rubber? When you rub a glass rod with silk, what is the state of the rubber? Give sketches, and describe concisely how you would prove experimentally the truth of your answers.

2. If you rub together a stick of sealing-wax and a piece of flannel, and then put them both on an electroscope, the leaves do not move. What happens to the electroscope if you remove (1) the flannel, (2) the sealing-wax? What would be the effect in each case of bringing near the electroscope a glass rod that had been rubbed with silk? (S. and A. Exam., 1879.)

3. If two insulated bodies, A and B, are rubbed together, and A becomes positively electrified, what is the electrical condition of B: (1) As to the kind of its electrification; (2) as to the amount of its electrification as compared with that of A?

4. A piece of sealing-wax is rubbed with flannel which is held by india-rubber gloves. The wax and flannel are placed on two separate electroscopes, which are then connected by an insulated metal wire. Describe and explain the behaviour of the leaves. (S. and A. Exam., 1890.)

5. Describe any experiment by which you could prove that when electrification of one kind is produced, the opposite kind is also produced in equal quantity. (S. and A. Exam., 1887.)

6. A rod of sealing-wax is rubbed with dry flannel. An uncharged pith-ball suspended by a silk thread is attracted when the sealing-wax is brought near to it, but is unaffected by the flannel. Would you conclude from this experiment that when sealing-wax and flannel are rubbed together the sealing-wax only is electrified? Give reasons for your answer. (S. and A. Exam., 1888.)

7. You grind some sulphur in a mortar and thus electrify it; you place some of the electrified powder on the plate of a gold-leaf electroscope; the leaves diverge. Why? since the sulphur is an insulator, and does not part with its electricity. You remove the powder by means of an insulator; what will occur, and why will it occur? (S. and A. Exam., 1869.)

8. A muslin bag containing sulphur and red lead finely powdered is suspended by a silk ribbon so that it hangs within a metal vessel which stands on the cap of an electroscope. When the bag is jerked the powders are shaken out through the muslin into the vessel and become electrified by friction. State and explain what effect (if any) is produced upon the electroscope. (S. and A. Exam., 1889.)

9. Give instances of as many other ways of producing electricity as you know of besides friction.

10. Give the names of all the substances that you may have tested or seen tested, in their frictional series order, positive to negative.

11. Draw an analogy between the simultaneous and equal generation of positive and negative electricity on the one hand, and any mechanical operation on the other.

LECTURE XXV.

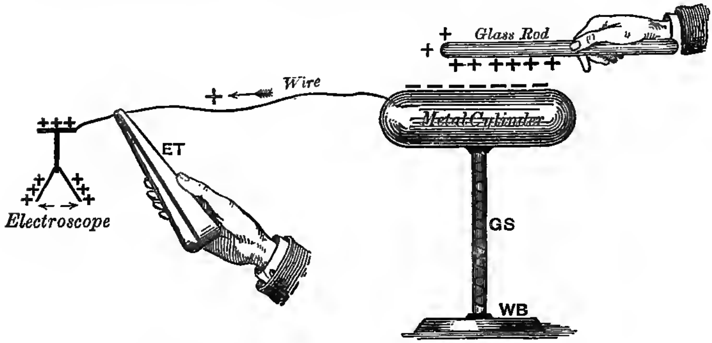
CONTENTS.—Electro-Static Induction—Charging a Gold-Leaf Electroscope by Electro-Static Induction—The Charge on an Enclosed Insulated Body Induces an Equal and Opposite Charge—Definition of Electro-Static Induction—The Electrophorus—How to Charge an Electrophorus—Theory of the Electrophorus—How to Charge an Insulated Conductor + or − by the Electrophorus—Questions.

IN Lecture VI., Part I., we experimented on MAGNETIC INDUCTION, giving definition and explanation, and in Lecture XVII., Part II., we did the same with ELECTRO-MAGNETIC INDUCTION. We shall now deal in a similar manner with ELECTRO-STATIC INDUCTION, and you will find that there is a great similarity between the actions of magnetic induction and electro-static induction. Consequently the student who grasped our treatment of the former results will have less difficulty in following the electro-static actions than he would have had by taking up this section in the first instance.

Electro-Static Induction.—EXPERIMENTS X.—(1.) Connect an insulated conductor * by an insulated wire to a small hole near the edge of the cap of a gold-leaf electroscope, as shown by the following figure. Bring a positively-electrified glass rod fairly over and near to the conductor. You at once observe that the leaves of the electroscope diverge. While the glass rod is held in this position, disconnect the wire from the electroscope and from the conductor by means of thoroughly well insulating ebonite tongs, ET, without permitting the wire to touch anything else until it is *fairly* freed from the electroscope and the metal conductor. Then remove the charged glass rod. Now test the charge on the electroscope by bringing the charged glass rod near the cap. Since you obtain greater divergence of the leaves, you have made certain that the electricity repelled from the metal conductor through the wire to the electroscope by the presence

* The metal conductor does not require to be solid. It may be made of thin sheet brass, tin, zinc, or iron, or of a piece of turned wood covered with tinfoil or gold-leaf. It should not have any sharp edges or points about it. The insulating support, GS, may be made of flint glass warmed and painted with shellac varnish (so as to prevent the deposition of moisture on the surface of the glass), and fixed into a wooden base, WB.

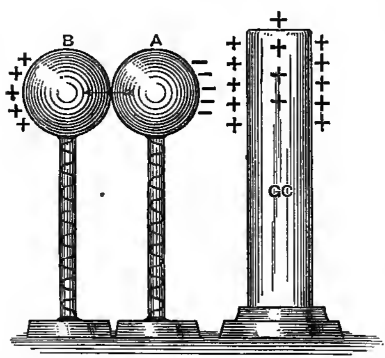
of the + glass rod is also *positive*. Next discharge the electroscope, and then transfer some of the charge left on the insulated metal conductor to the electroscope, until the leaves diverge to a convenient extent. Bring forward above the cap of the electro-



ELEMENTARY EXPERIMENT ON ELECTRO-STATIC INDUCTION.

scope an ebonite rod rubbed with flannel, which you know to be −, when you will obtain still greater divergence of the leaves. You have thus proved that the attracted charge on the metal conductor is −, or of *opposite* kind to that on the glass rod.

(2.) Take an ebonite rod charged *negatively* and bring it over the metal conductor when it is connected by the wire to the electroscope. Perform the remainder of the experiment in precisely the same way as before. You find that the *repelled* electricity is −, or of the same kind as that on the ebonite rod, and that the *attracted* electricity is +, or of the opposite kind.



POSITIVELY-CHARGED GLASS CYLINDER INDUCING A NEGATIVE CHARGE ON A, AND POSITIVE ON B.

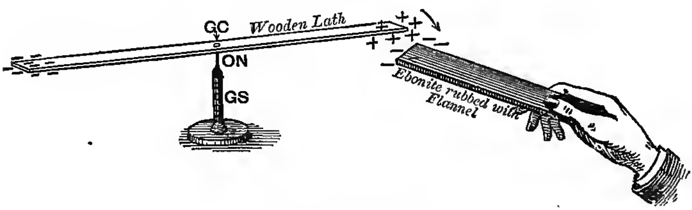
(3.) Take two insulated metal balls, or two apples, or two oranges, or two eggs, or, in fact, any pair of rounded conductors supported by insulating stems or suspended by silk threads. Place them side by side in contact with each other near a positively-charged insulator, such

as a glass cylinder rubbed with amalgamated silk, as shown by the accompanying figure.

First, Remove B to some distance from A.*

Second, Remove the inducing charge from A. Test the charge on B by the electroscope, and you find it to be +, or of the *same* kind as the inducing charge.† Test the charge on A, and you find it to be −, or of *opposite* sign to the inducing charge. You thus confirm your belief in the results obtained in Experiments X., Case (1).

(4.) Take the same or any other pair of insulated conductors, and again place them in contact with each other, but this time near a negatively-charged body, such as an ebonite rod rubbed with flannel. Perform the experiment as in Case (3), and you find that the repelled charge is of similar kind, and the attracted charge of the opposite kind, to that of the inducing charge, *i.e.*,



INDUCTIVE ACTION OF NEGATIVELY-CHARGED ROD ON AN INSULATED WOODEN LATH.

the charge on B would be − and on A + with a negative inducing charge next to A. This confirms Case (2).

(5.) Take the long insulated wooden lath already referred to in Lecture XXI., and present towards one end of it an ebonite rod rubbed with flannel. Before removing the rod or letting it come into contact with the lath, take a proof-plane, and place it on the end of the lath next the − ebonite. Transfer the proof-plane to a gold-leaf electroscope and test its charge. You find it to be +, or of opposite kind to that on the ebonite. Transfer a charge by the same means from the farther end of the lath to the electroscope. Test it, and you find this to be negative. You

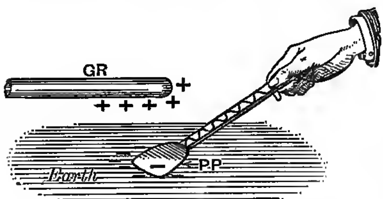
* If you removed the inducing charge first, then the induced charges on A and B would immediately combine, and you would find that both A and B were left neutral.

† In handling the above or any similar insulated conductor, *never* grasp the insulating stem close to the conductor, for fear that you may reduce the insulation of the stem by leaving a film of dirt or perspiration on it which would permit the charge to leak to earth. *Always take hold of the wooden base, or of the stem close to the base.*

now understand why the lath follows any charged body, viz., because the opposite kind of electricity is attracted to the end nearest to the inducing charge, and the same kind of electricity is repelled to the farther end.

Now referring back to Part I., Lecture VI., page 46. You cannot help observing the similarity between magnetic and electro-static inductions. In both, induction precedes attraction; for attraction only takes place in virtue of the induction causing the unlike electricity or pole to appear on the side *nearer* to the inducing force. There is, however, this difference between them, viz., that by electro-static induction you can cause a body to be charged with but *one* kind of electricity (+ or −), whereas by no means can you obtain a magnet with but one pole, N or S.

(6.) Take a + glass rod, and hold it over the lecture-table or any such earth-connected body. With a proof-plane touch the table without removing the glass rod, and by aid of the electroscope test the charge thus induced on the table and proof-plane. You find it to be −, or of opposite kind to that on the glass. Do precisely the same with a − ebonite rod, and you find the proof-plane shows +. Electricity of the *same* kind as the inducing charge has in each case been repelled to the earth, while electricity of the opposite kind is held *bound* by the inducing charge.



TESTING INDUCED ELECTRICITY ON AN EARTH-CONNECTED BODY.

Charging a Gold-Leaf Electroscope by Electro-Static Induction.—After studying these six simple experiments you will be in a position to thoroughly understand the series of actions depicted on the full-page illustration in Lecture XXII. Referring to that page, you observe that, starting with the electroscope in a neutral condition—

1. The inducing charge *attracts* the *unlike* and *repels* the *like* kind of electricity.

2. Separation consists in permitting the repulsion to earth of the *free like* kind, and keeping *bound* the *unlike* charge.

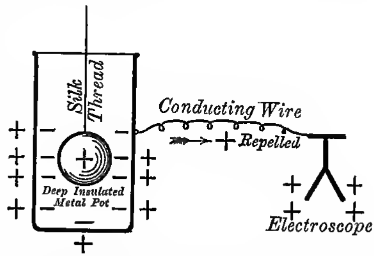
3. The charging now takes place by the removal of, *first*, the earth connection, and, *second*, the inducing charge.

4. In each case, the electroscope is left charged with electricity of *unlike* kind to that of the original inducing charge.

5. To discharge the electroscope and bring it back to the

neutral state, you have only to touch it with the finger or any earth-connected body, when the leaves come together again.

The Charge on an Enclosed Insulated Body Induces an Equal and Opposite Charge.—EXPERIMENT XI.—Connect a deep, hollow, well-insulated metal vessel by a long insulated wire with the cap of a distant gold-leaf electroscope. Take a metal ball and suspend it by a long length of the best insulating silk thread. Charge the ball, say, positively. Lower it gently inside the vessel, as shown by the accompanying figure. Observe that when the ball has been lowered so far inside the pot that it is just below the level of the rim, the divergence of leaves of the electroscope is not increased by lowering the ball still farther, or even when the ball reaches the bottom or touches the sides of the vessel. This shows you that as soon as the ball is well inside the vessel a charge is induced on the inner surface of the vessel exactly equal to the charge on the ball, but of *opposite* kind; and another charge on the outside of the vessel, also equal to the charge on the ball, but of the same kind. It is, therefore, not absolutely necessary to discharge the body in order to measure its charge, since, as shown by the above experiment, the potential of the enclosing vessel remains the same whether the body touches it or whether the body is merely let down inside.



FARADAY'S EXPERIMENT TO SHOW THAT A CHARGE INDUCES AN EQUAL AND OPPOSITE CHARGE.

If the charged ball had been removed from the hollow vessel without letting it touch the sides, then the leaves of the electroscope would have come together again; thus proving that the attracted – charge on the inside of the vessel exactly cancelled the repelled + charge on the outside when the cause of the induced charge was removed.

You are now in a position to understand the following definition of electro-static induction.

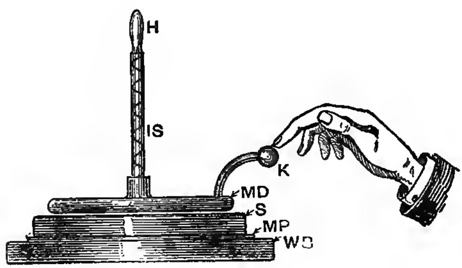
DEFINITION.—*Electro-static induction is the action whereby a charged body, surrounded by a dielectric,* evokes an equal and*

* Any insulating medium regarded as the seat of electro-static induction is called a *dielectric.* In our Advanced Course we shall have occasion to distinguish more particularly between the terms "insulating medium" and "dielectric," as well as to consider the inductive capacities of different dielectrics—*i.e.*, their respective capabilities for transmitting through them the electric stresses of induction.

*opposite charge on the inner surface of the enclosure containing the body and dielectric.**

The Electrophorus.—The instrument which bears this name is a mechanical arrangement for enabling a series of charges of electricity to be obtained by electro-static induction from one fixed charge produced by friction on an insulator. The first electrophorus was devised by Volta in 1775, and the word is derived from the two Greek words ἤλεκτρον (*ēlektron*), amber, and φερω (*pherō*), to yield or bear. It is one of the best examples of induction that we can offer at this stage, and consequently we invite close attention to its construction † and action.

From the accompanying figure and index to parts it will be seen that a lecture-table form of electrophorus consists of a metal



THE ELECTROPHORUS.

H	represents	Handle.
IS	„	Insulating stem.
K	„	Knob (metal).
MD	„	Metal disc.
S	„	Shellac or sulphur (insulating cake).
MP	„	Metal plate.
WB	„	Wooden base.

disc fitted with an insulating handle. The under surface of this disc should be a plane surface, and the edges carefully rounded. It is sometimes supplied with a discharging knob, but this appendage is not essential. The lower portion is composed of a shellac, resin, sulphur, ebonite, or vulcanite circular cake with a plain, clean, dry upper surface. This cake is glued to a metal plate or tinfoil fixed upon a wooden base.

* Or, *Electro-static Induction is the name given to the action and reaction which take place when the electric force springing from a charged body makes evident the latent electricity of a neighbouring conductor, without actual contact of the bodies.*

† See Appendix, how to construct a cheap electrophorus.

How to Charge an Electrophorus.—EXPERIMENT XII.—*Note the following figures in turn.*

Fig. 1. Flip surface S vigorously with cat's skin.

Fig. 2. Replace MD on S by H.*

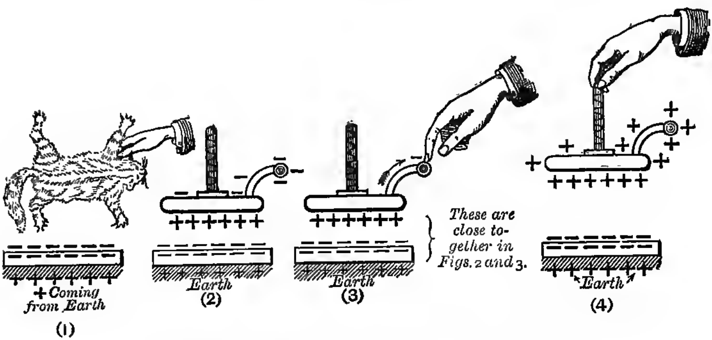
Fig. 3. Touch K with hand.

Fig. 4. Remove MD by H, and give the charge to anything.

Repeat operations 2, 3, and 4, until the charge on S has leaked away.

Theory of the Electrophorus.—*Note the above figures again.*

Fig. 1. The excitement produced by the cat's skin on S generates − electricity on the shellac, which attracts + *from* the earth to the under-surface of S and repels − *to* the earth. The − on S keeps the + bound so long as there is any − on S, and



FIGURES ILLUSTRATING THE CHARGING OF AN ELECTROPHORUS.

the reaction of this earth-induced + causes the − to soak into the shellac.

Fig. 2. The − on S attracts + to under-surface of MD and repels − to its upper side by electro-static induction.*

Fig. 3. Connecting K to earth permits the *free* − to escape.

Fig. 4. Lifting MD from S permits the + charge to distribute itself over the surface of MD.

How to Charge an Insulated Conductor + or − by the Electrophorus.—EXPERIMENTS XIII.—(1.) *To charge the conductor*

* The two plane surfaces lie quite evenly and very close to one another, touching only at a few minute points, and since the surface of the shellac is an excellent insulator, when these points have been robbed of their minute charges the electricity does not readily spread to them, so that the charge originally imparted to S is free to induce many successive charges on MD; in fact, until the charge on S has leaked or crept to earth. The distance between S and MD has been greatly magnified in figs. 2 and 3, to show the − and + signs.

positively.—On removing the + metal disc (see fig. 4), bring it into contact with the conductor. By repeating the processes (see figs. 2, 3, 4) many times, you can impart a large quantity of electricity to the conductor without reflipping the shellac cake; but the potential of the charge on the conductor can never rise above the potential of the charge induced on the metal disc.

(2.) *To charge the conductor negatively*.—On removing the + metal disc (fig. 4), bring it near to the insulated conductor. This attracts and binds – on the near side of the conductor. Now touch the conductor at any point with the finger or any earth-connected body; this lets the repelled free + electricity pass to earth. Then remove the metal disc from the vicinity of the conductor, when the latter remains *negatively* charged.

(3.) Or, if the insulated conductor be portable, bring it forward so that it may touch the knob K instead of the hand, when it will receive a – charge from the repelled – on MD. Repeat as in figs. 2 and 4, and, as just stated, several times, until you obtain all the charge required on the metal conductor.

LECTURE XXV.—QUESTIONS.

1. Give a clear definition of the terms "electric *conduction*" and "electric *induction*." (S. and A. Exam., 1878.)

2. If an electrified piece of metal is made to touch a gold-leaf electroscope, the leaves separate, and, on taking the metal away, they remain separate. But if the electrified metal is only brought *near* to the electroscope, and then taken away, the leaves separate when the electrified metal is near, but fall together when it is taken away. Why is there a lasting effect on the gold-leaves in one case, and only a temporary effect in the other case? (S. and A. Exam., 1886.)

3. What is meant by the term "insulated"? I bring a glass rod which has been rubbed with silk near an insulated brass sphere; what is the condition of the sphere while the glass is near it? What occurs when the glass is removed? (S. and A. Exam., 1868.)

4. I hold a dry glass rod which has been rubbed with silk near a brass ball, which is supported on a dry glass stand; what is the state of the ball? Supposing the stand which holds the brass ball to be moist instead of dry, what will occur? (S. and A. Exam., 1873.)

5. A stout stick of sealing-wax is stuck upright to a piece of wood, acting as a base; into the wax at the top is inserted a needle, and on to the needle is fixed an apple; near to the apple, but not in contact with it, is brought a rod of glass which has been rubbed by silk. What is the condition of the apple while the rod remains near it? What occurs when the apple is touched for a moment? What finally occurs when the rubbed glass is withdrawn? (S. and A. Exam., 1876.)

6. A glass rod which has been rubbed with amalgamated silk is held near to an insulated metal ball, and the side of the ball nearest to the glass momentarily touched, after which the glass rod is removed. Describe and explain the effect of each step in the experiment. (S. and A. Exam., 1889.)

7. A brass rod is supported horizontally by a dry glass stem, and a large strongly electrified metal ball is brought near one end of the rod (but not near enough for a spark to pass). The rod is then touched for an instant by the end of an earth-connected wire, and afterwards the ball is removed. Will it make any difference in the final electrical state of the brass rod whether the wire touches it at the end nearest the ball, at the end farthest from the ball, or at the middle? Give reasons for your answer. (S. and A. Exam, 1885.)

8. If you have a positively-charged brass plate and a piece of gilt paper fastened to the end of a dry glass rod, how could you charge the gilt paper with negative electricity? (S. and A. Exam., 1884.)

9. Two insulated metal spheres are brought so as to touch one another. A positively-electrified brass rod is brought near to one of the spheres, and, while it is there, the other sphere is taken away. The glass rod is now taken away. On bringing the spheres near together again, a spark passes between them. Give the reason for this. (S. and A. Exam., 1886.)

10. If you were given a negatively-electrified stick of sealing-wax and two metal balls mounted on insulating supports, how would you, with this apparatus, charge the balls with opposite kinds of electricity? How could you afterwards find out whether you had charged the balls as you intended, and whether their charges were equal or unequal? (S. and A. Exam., 1887.)

11. Three insulated metal balls, A, B, and C, are placed in a line, A and B in contact, C a little way off. C is positively electrified, and then A and B are separated. What are now the electrical states of A and B? (S. and A. Exam., 1884.)

12. A lath six feet long is supported at its centre on a dry glass tumbler. Below one end of the lath, and at a distance of some inches from it, are placed some scraps of gold-leaf or other light bodies. A glass rod electrified by friction is brought over the other end of the lath without touching it; the fragments of gold-leaf are immediately attracted. How is this attraction produced? (S. and A. Exam., 1877.)

13. A stick of sealing-wax having been rubbed with flannel, is found to be negatively electrified. How, by means of it, would you charge a proof-plane with positive electricity? (S. and A. Exam., 1886.)

14. A glass rod which has been rubbed with amalgamated silk is held just below the spout of a metal funnel from which shot drop one by one, without hitting the glass rod, into a cup of the same metal as the funnel. State and explain the result which may be observed—(1) if the funnel and the cup are each connected with a separate electroscope; (2) if they are both connected with the same electroscope.

15. Sketch an electrophorus. Explain its construction and action in full by a series of outline sketches.

16. What occurs when you whisk the resinous plate of an electrophorus with a fox's brush? The plate being excited, how would you obtain the spark of the electrophorus? (S. and A. Exam., 1878.)

17. Say exactly what you must do in order to get a succession of sparks from an electrophorus? (S. and A. Exam., 1885.)

18. A little pith-ball rests on a brass plate provided with a glass handle. The two are placed on a cake of resin which has been rubbed with a cat's skin. When the plate is touched by the finger and then lifted by the handle, the pith-ball jumps off the plate. Why? (S. and A. Exam., 1883.)

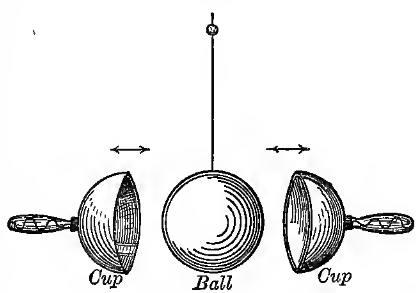
19. A piece of dry brown paper laid on a warm metal tray is rubbed with cat's skin. The tray is then placed on a dry glass tumbler, and the brown paper is removed. Explain how it is that you can now get a spark on bringing your knuckle near the tray. (S. and A. Exam., 1882.)

LECTURE XXVI.

CONTENTS.—Electro-Static Distribution of Electricity on Conductors—Electro-Static Charge Resides on the Surface—Electro-Static Charge Resides on the Outside Surface of Hollow Insulated Conductors—Distribution Depends solely on the Shape of the Conductor when otherwise Unaffected—Potential, Density, Electric Stress, and Action of Points—Law of Electro-Static Distribution—Questions.

Electro-Static Distribution of Electricity on Conductors.—Referring again to the definition of a conductor and an insulator as given in Lecture XXIII., we find it stated that if electricity is produced on or imparted to one part of a non-conducting body, the charge remains at that point or creeps over the surface *very* slowly in an indefinite manner; whereas, in the case of a conductor, the charge almost instantly distributes itself over the body in a perfectly definite manner, depending upon the shape of the body and its position with respect to other surrounding bodies. We shall in this lecture investigate experimentally the manner in which an electro-static charge is distributed over different forms of conductors, and state the law upon which this distribution depends.

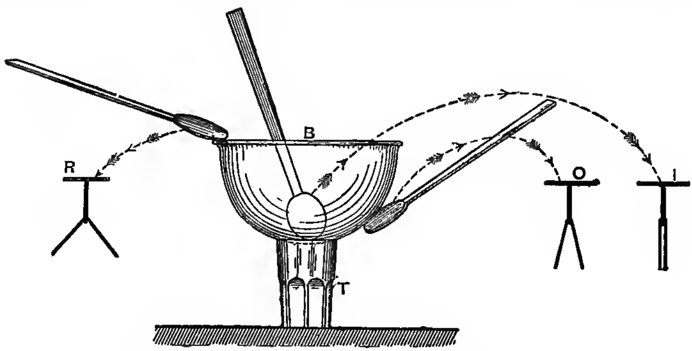
Electro-Static Charge Resides on the Surface.—EXPERIMENT XIV.—Take a metal ball suspended from a hook by a couple of feet of well-insulating silk thread. Electrify the ball by means of the electrophorus explained in the last Lecture, or by a charge from a Leyden jar (see next Lecture). Bring forward to the ball simultaneously two hemispherical uncharged metal cups, held by their insulating stems, until they meet and fit tightly on the ball. Remove the cups, and test them by the gold-leaf electroscope. You find that each of them is now charged. Test the ball by lift-



BIOT'S EXPERIMENT.

ing it to the electroscope by the silk thread, and you find that its charge is gone. The cups, when in contact with the ball, formed one conductor with it, and the mutual repulsive action of each portion of a charge for every other portion of the same charge forced the whole to the outside surface. It does not make the slightest difference to the result whether the ball be solid or made hollow of the thinnest metal, or even of wood, or, in fact, anything covered with tinfoil or gold-leaf; neither does it matter how thick or how thin the metal cups are, for the charge will always come to the outside surface.

Electro-Static Charge Resides on the Outside Surface of Hollow Insulated Conductors.—EXPERIMENTS XV.—(1.) Take a metal bowl, B, and place it upon a glass tumbler, T, varnished with shellac. Impart a charge to the inside or outside of the



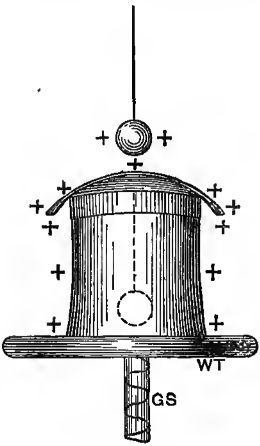
TESTING THE DISTRIBUTION OF A CHARGE ON A METAL BOWL.

bowl, it does not matter which. Now test for the relative distribution of the charge by means of a proof-plane and electroscope. You discover (as shown by the above figure) that no charge is found on the inside, I; a fair quantity is found on the round part of the outside, O, and the greatest quantity on the rim, R.

(2.) Take a hat and a metal pan. Place them on insulating stands. Impart a charge to them by means of a metal ball connected to a charged Leyden jar by a wire, as shown by the following figures. Test the distribution of the charge by the proof-plane and electroscope, when you will observe that *none* can be found on the inside, but that the whole charge has been self-repelled to the outside, and that the greatest density * is found on the sharp rims of these articles.

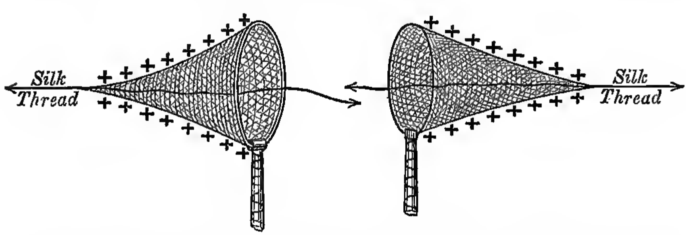
* *Electric surface density* is the quantity per unit-area, which we shall discuss in our Advanced Book.

(3.) Take a cotton bag or a butterfly gauze-net fitted to a wire hoop, supported by an insulating handle. Attach two well-insulating silk threads to the apex of the cone, as shown by the lower figures. Charge the net from a Leyden jar, and test, by



TESTING THE DISTRIBUTION OF A CHARGE ON HOLLOW BODIES.

the proof-plane and electroscope, the inside and outside of the net. You discover that the charge is found *only* on the outside. Now pull the silk string attached to the inside, keeping the other one taut, and thus turn the net inside out. Again test where the charge resides, and you find that *none* can be detected on the



FARADAY'S REVERSIBLE NET EXPERIMENT TO SHOW THAT AN ELECTRO-STATIC CHARGE RESIDES ON THE OUTSIDE OF A HOLLOW INSULATED CONDUCTOR.

inside, but that the whole has reversed its position with the reversal of the net, and is again found on the outside.

To test this point still further, Faraday built a large insulated cage, and went inside it with his most sensitive electroscopes,

He then had this compartment charged to such a potential, that long sparks of electric discharge were easily got from the outside. He could detect no signs of electrification inside the chamber due to any electrical charge or disturbance produced outside of it. This interesting and important fact shows that a metallic shell, however thin, entirely screens bodies inside it from external electrification, however great. On this principle it has been suggested that houses and powder-magazines may be thoroughly protected from lightning by simply having a few earth-connected metallic wires in the form of an open mesh placed around them. A person in a four-poster metallic bed, with a good heavy mosquito-curtain around it, should consequently be safe from any of Jupiter's thunderbolts.

(4.) *Exceptional case.*—If you again charge any of the hollow insulated conductors shown by the three previous figures, and then lower an *earth*-connected ball well inside them without touching the bottom or sides, you will find, by taking a proof-plane and touching the side or bottom inside near to the ball, that part of the charge has returned from the outside to the inside. Remove the earth-connected ball, and the charge is again self-repelled to the outside. The presence of the ball brings into play the action and reaction of induction, whereby the charge induces electricity of unlike kind on the ball and repels the like kind to earth by the wire. The absence of the ball not only permits the naturally self-repelling effect of the charge to force the whole of the electricity to the outside, but also leaves the field clear for this charge to act inductively on all surrounding outside objects, and thus bind itself more firmly to the outside surface.

Distribution Depends solely on the Shape of the Conductor, when otherwise Unaffected.—Experiments XVI.—(1.) Take an insulated sphere, as shown by the right-hand figure. Charge this sphere, and test the density of the electricity at any point by the proof-plane and the electroscope. You find it to be the same everywhere.

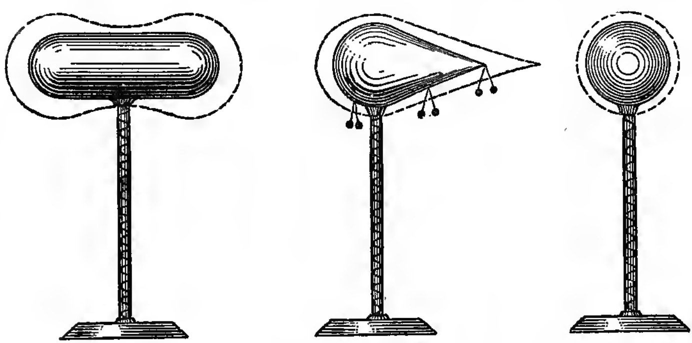
(2.) Take an insulated oblong conductor, as indicated by the left-hand figure. Test its charge at different parts.* You ascertain that the density is greater at the ends than at the middle.

(3.) Take a pear-shaped body, as illustrated by the middle figure. You obtain a very much greater quantity from the

* See the figure in Lecture XXII., page 215, illustrating this method of testing. We would remark, however, that in order to get anything like reliable results, the proof-plane should exactly fit the part it touches on the metal conductor, and be withdrawn at right angles, or normally to the surface touched.

pointed than from the round end or from the middle. Pairs of pith-balls suspended from different parts also serve to indicate roughly, by their various degrees of divergence, the relative densities at these places.

You observe the dotted lines surrounding each of these three figures. The distances between the surfaces of the bodies and the dotted lines are intended to graphically represent the *densities* of the charges at each part. If a small pith-ball were suspended by a long silk thread from a point in line with the vertical diameter of the charged sphere, so that the ball could swing round the sphere in the same plane as its horizontal diameter, then after the pith-ball touched the sphere and got charged, it would be repelled, and if set in motion round the sphere without being discharged, it would describe a circle whose centre



DISTRIBUTION DEPENDS ON THE SHAPE OF CONDUCTORS.

would coincide with the centre of the sphere, thus proving that the density was uniform along that path. If elevated a little, it would still revolve at a uniform distance from the sphere. In like manner, if the insulated pith-ball be brought near to and moved round the other charged bodies, then (after making contact with them) it will be repelled from them to various distances, depending upon the sharpness of the corners or pointed parts, thus indicating roughly the relative densities of the charge at each place.

Potential, Density, Electric Stress, and Action of Points.—We must not be drawn into a lengthy discussion of these terms at present. We shall have to consider them carefully in the Advanced Course, but we do wish to guard the student from supposing for a moment that the distances between the dotted lines

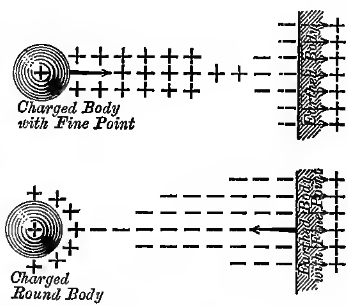
and the full lines in the three figures have anything whatever to do with the representation of the potential or pressure to which the bodies are charged. Neither have the several distances to which the pith-ball is repelled from a body anything to do with representing relative potentials, *for the potential is the same at all parts of a charged insulated conductor, whatever its shape may be.* If it were not so, then motion of the charge *would* take place; for whenever there is the *slightest* difference of potential between two points connected by a conductor, then electricity flows from the place at higher potential to the place at lower potential, until equilibrium is again established. The charge could not be static for a moment if the potential varied in consequence of the shape of the body. You find simply a greater density or quantity of electricity per square inch or per square centimetre of surface where the body is pointed than at places where it is well rounded, but the pressure of the electricity is the same at *all* points of the electro-statically charged body. Of course, the greater the pressure to which a given body is charged, the greater will be the density at every point on that body, but the distribution of the charge depends on the shape of the body *only*, so long as it is not affected by other bodies being near it. The moment that another body is brought near a charged one, then induction is set up, and the distribution may be altered. For example, bring the hand up near the charged sphere, and the density immediately becomes far greater on the side towards the hand, because a portion of the charge comes from the other parts of the sphere (in obedience to the law of induction), in order to attract as much of the unlike kind as possible * on the side of the hand immediately opposite to the sphere, and to repel an equal quantity of the like kind through the arm and human body to the earth. Take away the hand, and the distribution becomes definite as before. During the time that the hand was held near the charged body, an electric stress was transmitted between them, through the particles of air tending to attract them together. In the case of such fixed solid bodies, this stress tugs at their surfaces; but with solids, and even many liquids, the force of cohesion between their particles is sufficient to resist the electric stress unless the difference of potential be very great. If you, however, electrify a soap-bubble, you can observe a visible expansion produced in the bubble, due to the combined effect of the self-repulsion of every portion of the charge for every other portion, and the attraction between this charge and the induced charge on surrounding bodies. When the bubble is freed, it floats towards the nearest object with an

* Consistent with the position of surrounding bodies and the induction thereon.

accelerated velocity, depending on the fact *that the force of attraction is inversely proportional to the square of the distance between the attracting charges.*

EXPERIMENTS XVII.—(1.) Suppose you put a needle into any of the bodies (illustrated in the three previous figures), with the point of the needle sticking outwards, and hold the hand opposite to the point at a few inches distance whilst the insulated body receives a continuous charge at high potential. The hand experiences a tickling sensation, with the feeling as if a jet of cold air were being blown upon it. If this experiment be performed in the dark, a bluish brush-like light will be seen issuing from the needle-point towards the hand. If you stop charging the body, holding the hand in position for a short time thereafter, and then test the body by the electroscope, you will find that it has lost its charge.

(2.) If, instead of fixing the needle into the body, you held the needle in your hand with the point directed towards the body, the brush-like light would still proceed from the needle, and the body would also be discharged. These two experiments are explained by the following figures and remarks.



THE DISCHARGING ACTION OF POINTS.

Where the density of a charge is great, as at a fine point, the air in contact with the point becomes charged to the same potential; and since the cohesion between air particles is very small, whilst the repulsion between the several portions of the charge is great, the air is forced from the point and carries part of the charge with it by convection.* Fresh air comes into contact with the point, thus still further reducing the density of the charge on the body, until the whole of the electricity has been removed. The particles of electrified air meet with the inductively charged particles from the earth-connected body, and being oppositely electrified, they naturally cancel each other.

(3.) This interesting phenomenon may be shown graphically to a class by the deflection of the flame of a candle, C, placed between a needle-point stuck into the prime conductor, PC, of an electrical machine (or any positively-charged body yielding a

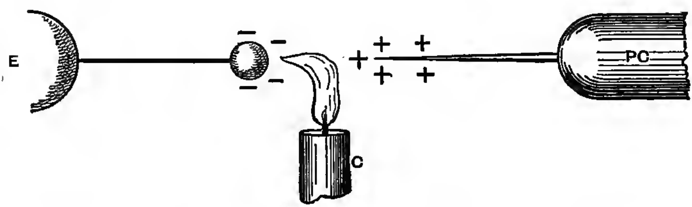
* Refer to the definition of this term at the end of Lecture XXIII.

continuous discharge of high potential) and an earth-connected body, E, as shown by the following figure. If you stick the needle into the earthed body, and leave the charged conductor round, the candle-flame will be deflected in the opposite direction, *i.e.*, still from the point, and towards the rounded body. This has been termed the *electric wind.* This wind moves *from* the side where the greatest density occurs, forcing the air by convection to carry off the charge.

(4.) Take a rubbed glass, ebonite, or other insulating rod, and move a needle-point held in the hand up and down within an inch or so of the rod. You will completely rob the insulator of its charge without touching it.

(5.) Stick a fine-pointed needle into a hole in the cap of a gold-leaf electroscope. Bring an electrified body near the point, and the electroscope will be charged without ever touching the cap. The electroscope will, however, be slowly discharged through the point; or if you bring your hand near the point, the electroscope will be quickly discharged.

You can now understand why it is necessary to have all parts



DISCHARGE FROM A POINTED BODY TO AN EARTH-CONNECTED ONE, ILLUSTRATED BY THE BENT FLAME OF A CANDLE.

of conductors that are intended to retain high-pressure electricity carefully rounded and as smooth as possible. Further, since minute hairs or particles of dust act in a similar manner to points and moving particles of air, it is imperative to keep your apparatus thoroughly clean. You need not attempt to get successful results from them if they are dirty and dusty, nor can you expect to retain a charge of high potential and great density on a body placed in a dusty, draughty atmosphere.

Without having time at this stage to prove by direct experiment Coulomb's law, upon which distribution of electricity depends, we shall, however, state it here, and return to the subject in our advanced course.

Law of Electro-Static Distribution.—*Every unit quantity of a charge repels every other unit quantity of the same charge, with a force varying inversely as the square of the distance between them.*

Unit-quantity of electricity is that which repels an equal and similar quantity at unit distance with unit force in air.*

* For definitions and values of fundamental and derived electro-static units, &c., see pp. 1 to 13 in Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables."

Lecture XXVI.—Questions.

1. A pewter pot is insulated and electrified; if you touch it at different parts with a penny stuck to the end of a rod of sealing-wax, what part of the pot will give the greatest quantity, and what part the least quantity, of electricity to the penny? (S. and A. Exam., 1881.)

2. The extremity, B, of a wire, AB, is attached to the plate of a gold-leaf electroscope. By means of an insulating handle, the other end, A, is placed in contact first with the blunt, and then with the more pointed, end of a pear-shaped insulated and electrified conductor. Describe and explain the movements of the leaves of the electroscope. (S. and A. Exam., 1889.)

3. Under what circumstances can you get a charge on a metal ball hanging by a silk thread by touching therewith the inside of a metal jar? (S. and A. Exam., 1884.)

4. A deep metal pot, positively electrified, stands on a glass stem. A metal ball hung by a silk thread is put in contact with a gold-leaf electroscope after being made to touch—(*a.*) First the *inside* and then the *outside* of the pot; or (*b.*) First the *outside* then the *inside* of the pot. State and explain the effect on the electroscope in each case. (S. and A. Exam., 1883.)

5. An electrified metal ball hung by a silk thread is allowed in one case to touch the inside of an insulated metal jar, in another case to touch the outside of the jar. What would be the result of afterwards connecting (1) the ball, and (2) the jar, with an electroscope? (S. and A. Exam., 1879.)

6. To protect a gold-leaf electroscope from being acted on when an electrical machine is at work near it, it is sufficient to cover the electroscope with a thin cotton cloth. How is this? (S. and A. Exam., 1886.)

7. An electroscope is surrounded by a cylinder of wire-gauze which is put to earth. If an electrified body is brought near to it, how will the leaves behave? Give reasons for your answer. (S. and A. Exam., 1890.)

8. A sharp point attached to a conductor, A, is held near an insulated charged conductor, B. What will be the effect on B if A is (1) insulated, (2) uninsulated? (S. and A. Exam., 1888.)

9. An orange, into which a sewing-needle has been stuck, point outwards, is suspended by a dry silk thread. A charged body is brought near to it (1) opposite the point of the needle, (2) opposite the side remote from the needle. State and explain the electrical effect in each case. (S. and A. Exam., 1887.)

10. An insulated electrified conductor can be discharged by bringing near it the point of a sharp needle held in the hand. Explain this. (S. and A. Exam., 1879.)

11. A glass rod is electrified by being rubbed with silk. A small sewing-needle, held in the hand, is then passed along the rod from end to end, the point of the needle not quite touching the glass. What effect is produced, and how do you explain it? (S. and A. Exam., 1890.)

12. An insulated conductor, A, is charged with electricity. Another conductor, B, earth-connected, is placed near to A. Is the induced charge on B greater than, equal to, or less than the charge on A? Give reasons for your answer. (S. and A. Exam., 1890.)

13. Under what circumstances is it possible to transfer the whole of the charge on a conductor to another insulated conductor? (S. and A. Exam., 1891.)

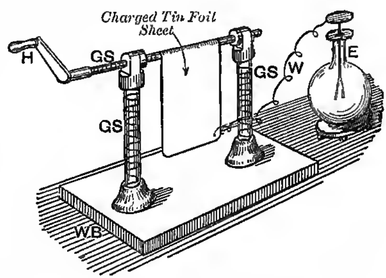
14. An insulated hollow metal vessel has a charge of positive electricity and is at some distance from other conductors. An uncharged metal ball supported by a silk thread is (1) introduced into the vessel without touching it, (2) connected momentarily with the earth, and (3) removed to a distance. State how its potential changes during these operations. (S. and A. Exam., 1891.)

LECTURE XXVII.

CONTENTS.—Surface-Density as Affected by Alteration of Area—Subdivision and Redistribution of Charges—Case of Equal Spheres—Case of Unequal Spheres—Definition of Capacity—Relation between Capacity, Quantity, and Potential Difference—Frictional Electrical Machines—Winter's Glass-Plate Machine—Construction, Action, and Theory—Earthing the Prime Conductor and Freeing the Earth Conductor—Short-Circuiting the Prime and Earth Conductors—Freeing both Prime and Earth Conductors—Other High-Pressure Electrical Machines—Questions.

Surface-Density as Affected by Alteration of Area.—

EXPERIMENTS XVIII.—(1.) Arrange your apparatus as shown by the accompanying figure.* Lower the tinfoil sheet to its full length by means of the handle, H. Charge the tinfoil from an electrophorus or Leyden jar. Roll up the sheet upon the insulated glass spindle, and note the increased divergence of the leaves. Lower the tinfoil again, and you observe that the leaves return to their former degree of separation.



ALTERING THE AREA AFFECTS THE DENSITY OF THE CHARGE.

(2.) Coil a quantity of very fine flexible wire, tinfoil ribbon, or a chain with small links, upon the cap of your electroscope. Charge the electroscope until the leaves diverge to a moderate degree. Now lift the wire, ribbon, or chain higher and higher with an insulated rod, but without breaking contact with the electroscope. You see that the leaves gradually come together. Lower the conductor again, and the leaves return to their former divergence.

(3.) Charge an electroscope. By means of an insulating handle or tongs place an unelectrified hat or tin can upon the cap. Note that the leaves decrease in divergence.

* An improvised arrangement, held in the hand, consisting of an ebonite or glass rod, from which hangs a sheet of tinfoil weighted at the lower end, will do. Before and after rolling up tinfoil, transfer charges to the electroscope, and compare the increased density by the greater deflection.

From these simple experiments you naturally conclude that, in a general way, the density with a fixed quantity varies inversely as the area.

Subdivision and Redistribution of Charges.—If we remove part of a charge from an isolated conductor by a proof-plane to a distance beyond reach of their electric fields,* then the charge redistributes itself over the surface of the conductor in the same definite manner as the original charge, but at a reduced density.

Case of Equal Spheres.—Suppose that you take two isolated spheres of *equal* size, and charge one of them with 10 units (of quantity), then bring it into contact with the other uncharged sphere, and finally separate them; you find on testing them that the charge has been subdivided into two equal quantities of 5 units each. Or if both the equal spheres are charged to begin with, then the electrifications mix in the arithmetical mean of their sum. For example, let one sphere have a charge of + 40 units, whilst the other has one of + 20 units, then, after contact and separation, each will have a charge of + 30 units.

$$\text{For, } \frac{40 + 20}{2} = +30$$

Again, let one sphere have a charge of + 40 units and the other − 20. After contact and separation each will have + 10 units.

$$\text{For, } \frac{40 - 20}{2} = +10$$

Case of Unequal Spheres.†—In dealing with the subdivision of charges between spheres of unequal size, we have to take into account their respective *capacities*.

To render the meaning of this term as clear as we can, from an elementary point of view, let us draw an analogy. Suppose you take two air-tight vessels, one *twice* the volume or *capacity* of the other, each vessel being fitted with a stop-cock. Suppose that you charge the larger vessel with 30 units weight of air at 30 lbs. (or units) of pressure on the square inch, and that you extract all the air from the smaller one, or leave it at 0 lb. pressure on the square inch or a perfect vacuum. Now connect the two vessels together by a very short small pipe, whose volume or capacity may be neglected. Open the two cocks, and the air rushes from the larger to the smaller vessel until equilibrium takes place—*i.e.*, until both are charged with air at the *same* pressure. Shut the two cocks and disconnect the pipe. Test the quantity of air in

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* The *electric field* is the region or medium surrounding an electrified body through which the electric stresses are transmitted.

† Elementary students may leave out the following small-print remarks and questions.

each by careful weighing, and the pressure by a gauge, when you will find that the *quantity* originally in the larger vessel has been distributed between the two vessels in direct proportion to their *capacities*, and that the pressure has been reduced in the ratio of the sum of the capacities of both vessels to the capacity of the larger vessel.

For,

Sum of caps. : Cap. of larger : : Sum of Quantities : Final qty. in larger.
$(2+1) : 2 :: 30 : x$

$$x = \frac{2 \times 30}{(2+1)} = 20 \text{ units.}$$

Sum of caps. : Cap. of smaller : : Sum of Quantities : Final qty. in smaller.
$(2+1) : 1 :: 30 : y$

$$y = \frac{1 \times 30}{(2+1)} = 10 \text{ units.}$$

$$\therefore \quad \frac{x}{y} = \frac{20}{10} = \frac{2}{1} = \frac{\text{capacity of larger.}}{\text{capacity of smaller.}}$$

The capacity of larger vessel being twice that of smaller one, it contains after redistribution twice the quantity of the smaller.

And,

Sum of caps. : Cap. of larger : : Press. in larger : Press. in both.
$(2+1) : 2 :: 30 : z$

$$z = \frac{2 \times 30}{(2+1)} = 20 \text{ lbs. press. in each.}$$

The pressure is reduced from 30 lbs. to 20 lbs., i.e., as 3 to 2, or in the ratio of the sum of the capacities of both vessels to the capacity of the larger.

If we take two conductors of the same shape but of different size, and charge the smaller from the larger, the charge will divide between them in quantities directly proportional to their capacities, and the potential or pressure will fall in the ratio of the sum of their capacities to the capacity of the larger; for by

DEFINITION.—*The capacity of a conductor is the quantity of electricity required to charge it to unit potential.*

Let K denote capacity;* Q, quantity; and V, the potential; then

$$K = \frac{Q}{V}; \; Q = VK; \; V = \frac{Q}{K}$$

(*The quantity of a charge is therefore equal to the potential difference multiplied by the capacity.*) Now the *Capacities* of spheres are *not* proportional to their surface-areas,† *but proportional to their radii.* The proof of this statement is too advanced for the present course, but the student will understand from what he learned in the last Lecture, that if a very small uncharged sphere be brought into contact with a charged one, then the smaller virtually forms a pointed end to the larger, and consequently the density is greatest thereat.

* It has become customary for British electricians to use the letter K to denote *capacity* (phonetically pronounced Kapacity), since the letter C is reserved by them for the term *current*.

† The surface-area of a sphere is $= 4 \pi r^2$, where π is the constant ratio of the circumference to the diameter, and r is the radius, therefore the surfaces of spheres are proportional to the squares of their radii.

On removal, the smaller one carries with it this greater density. The potential of the large one is slightly reduced until both are equal.

For example, take a sphere of 2 inches radius charged with 30 units of quantity, and bring into contact with it (by means of a long fine wire) a sphere of 1 inch radius. What will be the total *quantity* and the *density* on each sphere after separation?

Sum of caps.	:	Cap. of larger	: :	Sum of qties.	:	Final qty. on larger.
Sum of radii	:	Radius of larger	: :	Sum of qties.	:	Final qty. on larger.
$(2+1)$	:	2	: :	30	:	x

$$\therefore\ x=\frac{2\times 30}{(2+1)}=20 \text{ units.}$$

This leaves 10 units for the smaller one.

Or the ratio of their charges $=\frac{20}{10}=\frac{2}{1}=\frac{\text{radius of larger.}}{\text{radius of smaller.}}$

The total quantity on the large one is double that on the small one.

But as we saw before, Density $=\frac{\textit{Total quantity on surface.}}{\text{Area of surface.}}$

$$\frac{\text{Density on larger}}{\text{Density on smaller}}=\frac{\frac{20}{4\pi r_1^2}}{\frac{10}{4\pi r_2^2}}=\frac{\frac{20}{r_1^2}}{\frac{10}{r_2^2}}=\frac{\frac{20}{4}}{\frac{10}{1}}=\frac{5}{10}=\frac{1}{2}$$

The density on the larger is but half that on the smaller, or *inversely as their radii.* Had we used spheres of greater disparity in size, the density on the small one would have been proportionately greater; thus proving the effect of points in accumulating a charge on and near them.

Again, let the potential be V, which the larger sphere had before contact, then after contact and separation it would have been reduced to v, thus:—

Sum of caps.	:	Cap. of larger	: :	Potential of larger	:	Potential of both.
$(2+1)$	:	2	: :	V	:	v

$$\therefore\ \frac{V}{v}=\frac{(2+1)}{2}=\frac{3}{2}$$

The potential has been reduced in the ratio of 3 *to* 2, *or in the ratio of the sum of their capacities to the capacity of the larger.*

Note.—We specially desire you to carefully compare these two sets of arithmetical examples, the one on air and the other on electricity, where capacity (or volume) pairs with electrical capacity, weight or quantity pairs with electrical quantity, and pressure pairs with electrical potential. Further, you see that electrical density has no corresponding parallel. Electrical density is, however, proportional to the potential, when the area and capacity of any particular body do not vary; for Density $=\frac{\text{Quantity}}{\text{Area}}$ or $D=\frac{Q}{A}$ and $V=\frac{Q}{K}$, *i.e.*, the density and the potential are *both* proportional to the quantity when the area and capacity do not vary. The density of air is also proportional to the pressure.

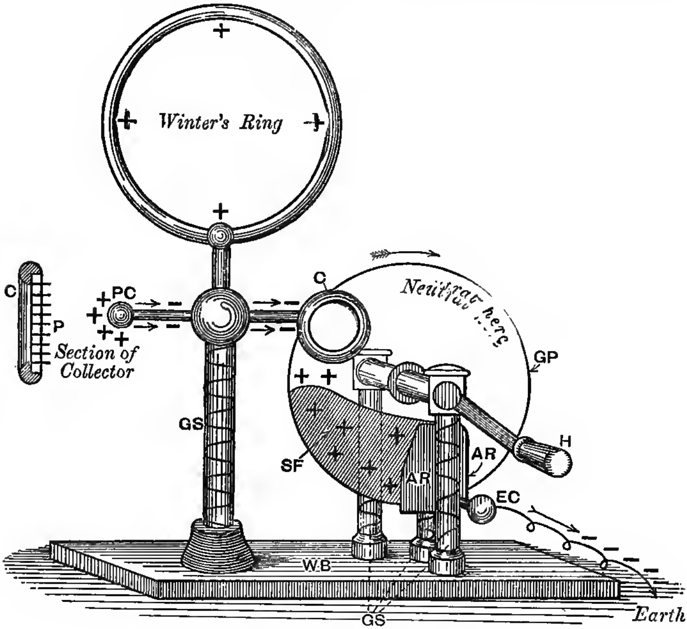
Frictional Electrical Machines.—The student will now be able to understand thoroughly machines of this type, which have been

devised for obtaining greater quantities of electricity than can be procured by the rubbing of a rod held in the hand or by an electrophorus. From first to last there has been a variety of forms; but they all consist of three main parts, the rubber, the rubbed body, and the collector of electricity. Since they are all explainable by the same system of reasoning, we shall select but one form, viz., the Winter's plate machine. Before describing this piece of apparatus we may remark that the first frictional machine was constructed by Otto von Guericke of Magdeburg in A.D. 1671, the same person who invented the air-pump. It consisted of a ball of sulphur fixed by an axis to bearings and turned by a handle by one person whilst another pressed his dry hands on the ball. This naturally excited the ball negatively, whilst the positive electricity escaped to earth through the hands. A chain hung from an insulated bar made contact with the other side of the ball, and thus the negative electricity was collected and led where desired for experimental use. Sir Isaac Newton (or Hawksbee about 1709) substituted a glass globe for the sulphur one. Boze in 1741 added a prime conductor. Professor Winkler of Leipsic first used a leather cushion instead of the hand-rubber. Gordon of Erfurt improved on the globe by adopting a glass cylinder. About 1760 Planta and others employed glass plates. More recently ebonite plates have been used with success.

Winter's Glass-Plate Machine.—*Construction.*—From the following figure and index to parts you will see that this apparatus in its modern form consists of a circular glass plate, GP, about 2 feet in diameter by $\frac{3}{8}$ inch thick, through the centre of which is bored a circular hole about $1\frac{1}{2}$ inch diameter. A strong spindle with enlarged screwed central boss is passed through this hole and secured to the plate by a brass nut on each side, faced with india-rubber washers. The spindle is carried by two bearings insulated from the wooden base, WB, by glass supports, GS.* A handle, H, is fixed to one end of the spindle by means of a pinching pin. Between the two glass supports for the bearings there is fixed to the base another glass upright terminating in two strong wooden flanges, one on each side of the glass plate. These flanges serve as a backing for the removable wooden frames,

* These supports are usually covered with the best shellac varnish, in order to prevent the deposition of moisture on their surfaces. Moisture would reduce the insulation, and thus lessen the efficiency of the machine. The insulation of *all* the glass supports should be carefully tested by the gold-leaf electroscope before the machine is used, especially if it has been laid past for a time. If found deficient, the shellac should be removed with spirits of wine, the glass supports rubbed hard with flannel until they become thoroughly clean and warm, and then revarnished with the best insulating shellac varnish freed from water.

which are faced with amalgamated leather, technically termed the rubbers. On the back sides of these rubbers are fixed strong bent brass rings making contact with the earth-conductor sphere, EC. This earth-conductor is connected to earth by a chain or a copper wire, fixed, if necessary, to the nearest gas or



WINTER'S PLATE-GLASS MACHINE.

WB	represents	Wooden base.
GS	,,	Glass supports.
EC	,,	Earth-conductor.
AR	,,	Amalgamated rubbers (*one on each side*).
SF	,,	Silk flaps (*one fixed to each rubber*).
GP	,,	Glass plate.
H	,,	Handle (for turning the plate, GP).
C	,,	Collectors (one on each side, see section).
PC	,,	Prime conductor (*to which is attached Winter's ring or condenser*).

water-pipe. The springs also serve by their elasticity to keep the rubbers pressed firmly on each side of the glass plate, even although the plate should be a little out of the truth. Silk flaps, SF, suspended from whalebone or ebonite rods attached to the wooden frame of each rubber, serve to protect the glass

plate where it is + charged, from attracting dust particles or hairs, which would dissipate the charge into the atmosphere before the electricity reached the collector, C. The collector is formed of two rings of wood (one on each side of the glass plate) having pin-points, P, projecting from brass liners sunk into them, as shown by the separate sectional view of the collector. When the rings are in position, these points face the glass plate (within half an inch of the same), and are connected to the prime conductor, PC, by horizontal brass rods screwed into the large brass ball fixed on the top of the long left-hand glass support, GS. In the upper side of this ball is bored a tapered hole to receive the shank of a metal ring covered with wood, termed Winter's ring.

Action and theory.—On turning the handle, H, in the direction of the arrow shown on the top of GP, the friction between the amalgamated rubbers, AR, and the plate, generates + electricity on the glass and − on the rubbers. The − flows to earth or mixes with, and is neutralised by, + from the earth through the conducting chain or wire, thus keeping the rubbers *always neutral.* The + being prevented from dissipation into the air by the silk flaps, SF, adheres to the glass until it comes opposite to the comb or points, P, of the collector, C, where it induces an equal quantity of − electricity of great density on the points, repelling + to the prime conductor and the Winter's ring. The − streams off the points towards the + on the plate, where it neutralises or cancels all the + thereon, thus leaving the plate *neutral* on its upper side, until it comes round to the neutral rubbers again, when the same action is repeated. The Winter's ring is simply a crude device for enlarging the surface and capacity of the prime conductor. It may be replaced by a condenser or Leyden jar (see next Lecture).

Earthing the Prime Conductor and Freeing the Earth-Conductor.—If you desire to obtain − electricity from this machine, all you have to do is to remove the earthing chain or wire from EC to PC. The − electrification of the rubbers charges EC negatively, whilst the + on the glass attracts − from the earth through the chain PC and the points P. If a large quantity is desired, then EC should be connected to one side of a condenser or Leyden jar, whilst the other side of the jar is put to earth (see next Lecture).

Short-Circuiting the Prime and Earth-Conductors.—If the prime and the earth-conductor of the machine be connected together by a conductor, or "*short-circuited,*" as it is technically termed, then *there will be no free charge;* for the + from the prime conductor is *entirely* conveyed to the equal and opposite −

of the earth-conductor, whereby they cancel each other, leaving the prime conductor neutral. If both are simultaneously connected to earth, then the latter furnishes an equal quantity of − to kill the + generated on the prime conductor, and an equal quantity of + to kill the − produced on the rubbers, thereby rendering the prime and earth-conductors neutral.

Freeing both Prime and Earth-Conductors.—The rubbing of glass by the amalgamated rubbers can but produce a certain total difference of potential, which limit can *only* be reached when the insulation of the machine is perfect. Owing to leakage, the potential attained is generally less than the maximum possible. When the earth-conductor is connected to earth, this difference of potential is entirely +, or above the zero of the earth; but if the earth-conductor be *also* free and thoroughly insulated, then this total difference of potential is made up by a certain + potential above the earth on the glass plate and an equal − potential below the earth on the rubbers. When this total difference of potential has been reached, then the machine will stop generating electricity, for the prime conductor will refuse to discharge more − on to the glass. There is, in fact, only a small limited − charge on the rubbers, and + on the prime conductor, owing to the low capacity of the rubber. If we draw sparks from the prime conductor, or connect it for an instant at a time to earth, then we soon reach a condition of affairs where the whole available difference of potential is negative or below the potential of the earth, and the prime conductor will give off no further sparks. If you connect by a wire one free conductor with an insulated body, and the other with another insulated body (such as the outside and inside coatings of an insulated Leyden jar or condenser, see next Lecture), then these bodies or coatings will also be charged to the full difference of potential which the machine can produce, whenever a sufficient number of turns has been given to the glass-plate to fill the additional capacity of the insulated bodies.

Other High-Pressure Electrical Machines.—Many kinds of electrical machines have been invented of late for producing electrification at a high pressure. Most of these (such as the Varley, Töpler, Holtz, Voss, and Wimshurst) come under the term "influence" machines; that is to say, their action when started depends upon induction. We must, however, defer their explanation until the Advanced Course of Lectures, partly from the fact that the theory of their action demands a more thorough grounding in the principles of induction than we have been able to give in an Elementary Course, but chiefly because there is not space for them within the limits of this Manual.

LECTURE XXVII.—QUESTIONS.

1. How is the surface density affected by alteration of area? Illustrate your answer by describing an experiment.

2. Supposing you charge an insulated sheet of tinfoil having 100 square inches surface, and then roll it up to an external superficial area of 10 square inches, how is the density affected by the reduced surface? Sketch arrangement of the apparatus, and prove your answer.

3. How does a charge divide between two equal isolated spheres?

4. How does a charge divide between two unequal isolated spheres? Give an arithmetical example.

5. Define capacity, quantity, and potential difference, and state the relation that subsists between them in the case of electro-static charges of electricity. How is the density of a charge affected by altering the potential difference?

6. Sketch and describe by an index to parts, Winter's plate-glass frictional machine. Explain how it is worked, and give a theory of its action.

7. How is a Winter's machine affected by—(1) Earthing the prime conductor and freeing the earth-conductor; (2) Short-circuiting both; (3) Freeing both conductors?

8. Describe the construction of a simple form of electrical machine. (S. and A. Exam., 1889.)

9. When the handle of an ordinary frictional machine is turned, sparks can be drawn from the prime conductor. Explain carefully how the prime conductor becomes charged with electricity. (S. and A. Exam., 1888.)

10. The prime conductor of an electrical machine has a long brass rod projecting from it; from the end of the rod a pith-ball hangs by a damp cotton thread, and a pin is driven into the pith-ball up to its head, so that the point projects on the other side. How and why does the ball move when the machine is turned? (S. and A. Exam., 1884.)

11. In the common plate or cylinder electrical machine the conductor is of rounded shape at all parts, except where it comes nearest to the plate or cylinder, but here it is provided with sharp projecting points. What reason is there for this arrangement? (S. and A. Exam., 1883.)

12. Show why it is necessary, in order to obtain a succession of sparks from the prime conductor of an electrical machine, that the rubber should be connected with the ground. (S. and A. Exam., 1880.)

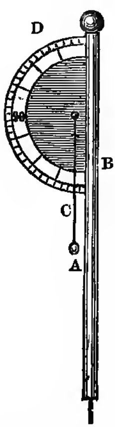
13. Could an electrical machine be made to act if it had a metal plate instead of a glass plate? If not, why not? If it could, show how. (S. and A. Exam., 1880.)

14. The ebonite portion of an electrophorus is charged with electricity. What means would you take to completely discharge it? (S. and A. Exam., 1891.)

LECTURE XXVIII.

CONTENTS.—Experiments with the Winter Machine Illustrating the Action of Discharges, Points, Heat, and Flame—Definitions of Discharge, Disruptive Discharge, Continuous Discharge or Current, Electric Glow, Wind, Brush, Spark, and Vacuum Tube—Condensers and Condensation of Electric Energy—Charging a Condenser—Discharging a Condenser by Removing the Free Charges—Short-Circuiting or Discharging a Condenser at Once—Definition of Specific Inductive Capacity—Practical Uses of Condensers—The Leyden Jar—Charging and Discharging the Leyden Jar—Seat of the Charges in a Condenser or Leyden Jar—Joining up the Leyden Jar to form a Battery for Quantity and for Potential—Final Remarks—Questions.

Experiments with the Winter Machine.—A great variety of interesting and instructive experiments may be performed by aid of this machine. We shall now mention a few of them. EXPERIMENTS XIX.—(1.) *Illustrating the action of discharge and points.*—With the prime conductor free and the earth-conductor connected to earth, introduce into a small hole in the upper side of the prime conductor the metal stem of a Henley's quadrant electrometer.* Turn the handle with one hand (or, better, get an assistant to turn it), and when the pointer of the electrometer is well deflected from zero, bring the knuckle of the other hand or an earth-connected metal sphere or other rounded body gradually towards the prime conductor. By induction the + electricity collected on the prime conductor attracts – to the hand or earthed body, and when they are within sparking distance of each other (some 4 or 5 inches, if the machine is in good order), a discharge takes place between them, accompanied by a snapping noise and a painful sensation if the hand and human body form the path to earth.



HENLEY'S QUADRANT ELECTROMETER.

* This simple apparatus, as shown by the above figure, consists of a metal rod, B, with a graduated quadrant, D, fixed to its upper end, and a pith-ball, A, suspended from the centre of the quadrant by a very light insulating

Notice the form of this discharge, and you see that it is of a zigzag (WWW) nature.

Bring the earthed body nearer to the prime-conductor and the spark becomes wavy, and seems to bifurcate like the branches of a leafless tree.

Bring it still nearer, say about an inch distant, and the spark takes a straight-line path. It is, moreover, almost continuous, especially if the Winter's ring be removed, which naturally reduces the capacity of the machine. The sparks occur more frequently, the report is not so loud, and their pungency is not so great, *because a smaller quantity of electricity has been accumulated and discharged each time.*

Each time that a spark occurs you observe that the pith-ball falls towards zero, showing that the potential of the machine has been reduced by the combination of the + and induced − charges causing the prime conductor to become almost or quite neutral. Remove the earthed body and cease generating electricity. You notice that the pith-ball comes gradually to zero. The more slowly that it does so, the better is the insulation of the machine as a whole, for it proves that leakage is not taking place rapidly over the surface or through the main glass support.

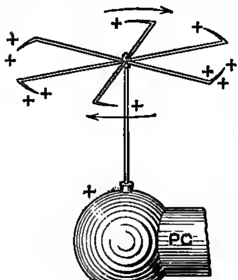
(2.) Replace the Winter's ring, if removed for demonstrating the continuous and rapid discharge in a straight line, and bring forward a fine-pointed instrument, such as a darning-needle, held in the hand towards the prime conductor. Now work the machine again. You observe that the electrometer shows scarcely any deflection, that the discharge takes place quietly, and not in the zigzag disruptive manner that you saw with the rounded body. Further, you hear only a hissing sound, you see but a bluish brush-light springing from the point of the needle, and you feel little or no sensation (certainly no startling shock), as in the former first and second cases.

The reasons for this entirely different action between points (or a pointed and a rounded body), and the gradual accumulation of energy with final breaking down of the air dielectric in the case of discharge between two rounded bodies, will be easily understood if you apply the knowledge gained from Lecture XXVI. about the action of points, and the convection by the air due to the same.

(3.) Place a star-pointed whirligig (like that shown by the following figure) on the prime conductor, PC, of the machine.

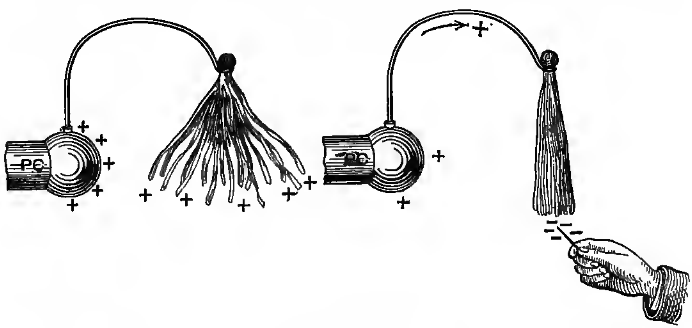
pointer, C. When the rod B is charged from the prime conductor, it first attracts A and then repels it to a distance varying with the potential of the charge; consequently the angle through which the pointer is deflected from zero roughly indicates the potential of the prime conductor.

Turn the handle, and you immediately see that the star revolves in the *opposite* direction to the way in which the sharp points are fixed. This is due to the inertia and consequent reaction of the fixed air on the air repelled from the points (just as the water in Barker's mill or reaction turbine causes it to revolve), as well as to the repulsion between the + repelled air and the + charged points of the star.



HAMILTON'S ELECTRIC WHIRLIGIG.

(4.) Cut up a piece of tissue-paper into narrow, long strips. Tie them together at one end, and to the knob on a stiff wire, extending about two feet from the prime conductor of the machine. Turn the handle, and observe how the similarly-charged strips repel each other. Bring beneath and towards them a darning-needle, presenting the point of the needle to the tassel. Observe how they instantly come together. Cover the point of the needle with the tip of the finger, and see how they diverge to a certain extent. Withdraw the hand, and you find that they spread out



EXPERIMENTS WITH THE FRICTIONAL MACHINE, SHOWING THE ACTION OF POINTS.

as before. The induced – electricity, of great density streaming off the point of the needle, cancels the + electricity on the strips and renders them neutral.

(5.) Take a carved wooden head covered with long, dry, clean hair. Fix it to the prime conductor. Work the machine, and see how the hair stands on end. Pass the palm of the hand to and fro at some distance above the hair, and see how it waves to and fro in sympathy. Hold a pointed needle towards the hair,

and watch how it falls down. A student who has long unoiled hair, if placed on an insulating stool, and connected to the prime conductor by a wire, will suit very well. He will feel very little pain, even though sparks be taken from his nose, because the hair of his head and the wool of his coat cause a large portion of the charge to be given off without disruptive discharge.

ELECTRIFIED WOODEN HEAD WITH UNOILED HAIR.

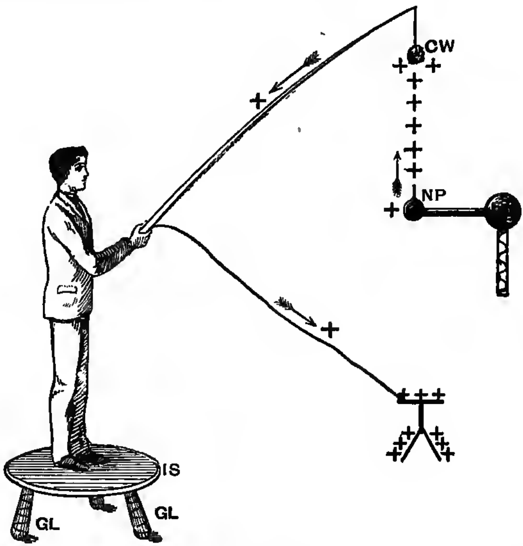
Action of Heat and of Flames in Discharging Electric Charges.—EXPERIMENT XX.—(1.) Stick a match into a small hole in the cap of a gold-leaf electroscope. Light the match, and you will be unable to charge the electroscope. The flame discharges the electroscope as quickly as it is charged.

(2.) Bring a red-hot ball or a lighted match near the cap of a charged gold-leaf electroscope, and either will quickly cause it to be discharged.

(3.) Stand upon an insulating glass-legged stool. Hold in your hand a fishing-rod, or long rod connected at the butt-end by a wire with a gold-leaf electroscope, and at the point by a copper wire, CW, with a piece of cotton-waste steeped in spirits of wine, as shown by the following figure. Light the spirits of wine, and bring it over a needle-point, NP, stuck vertically into the prime conductor, PC, of an electrical machine. Watch how the leaves diverge the instant that the machine is worked. You may hold the flaming cotton-waste ten, or even more, feet away from the needle-point, and yet you will catch electricity by this method of fishing for it. On first presenting the flaming cotton-waste towards the prime conductor, no doubt a certain quantity of − electricity is induced, but this is soon cancelled by the + streaming off the point, until a column of + electricity actually passes up through the air by convection, and being collected by the flame, it charges the rod, person, and electroscope with + electricity. This may easily be proved by nipping off the conducting wire with a pair of insulating tongs, and testing the charge on the electroscope by a glass rod rubbed with silk. If you stop the machine, and still hold the rod as shown in the figure, the electroscope, operator, and rod will soon be discharged by the flame. The fact is, that the flame offers so many points, and causes such a circulation of air and particles of dust to and from it, that the charge is dissipated in a much shorter time than by a mere point.

The ancients were not so very far wrong, therefore, when they lighted fires upon the appearance of lightning and thunder, thinking to appease the wrath of Jupiter, for there can be no doubt that a fire or the heated gases rising from a factory chimney serve the purpose (as just shown) of dissipating a charged cloud, quite as well as, if not better than, a pointed lightning conductor connected with the earth can do it.

We might multiply these experiments to almost any extent,



TESTING FOR ELECTRICITY, ILLUSTRATING THE ACTION OF POINTS AND FLAME.

but there is no necessity for doing so here. Enough has been given to impress the student with disruptive discharge as well as the silent discharging action of points and flames, and to enable him to understand the following definitions.

DEFINITIONS.*—*Discharge.*—When two conductors charged with opposite electrifications are made to touch each other, it is found that at the moment of contact there is a disappearance of electrification, positive neutralising negative; and that after contact the *total electrification* of both kinds, reckoned without regard to sign, is *less* than before. This process of neutralisation is accompanied with evolution of heat and other physical changes in

* These definitions are by Dr. Fleming, convener of the Institute of Electrical Engineers' Committee on Nomenclature and Notation.

the conductors, and in the surrounding air or insulating medium, and is called *discharge.*

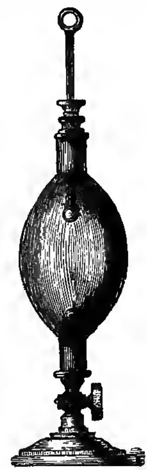
Disruptive discharge.—When discharge is of brief period, and takes place through or in an insulating medium surrounding the conductors, this is called *disruptive discharge.* In the case of disruptive discharge, the dielectric is ruptured or split, though, of course, the fracture is only permanent in the case of solid insulators.

Continuous Discharge or Current.—By certain arrangements it is possible to renew the opposite electrifications of the conductors as fast as the charge removes them, and then we get a continuous discharge or current of electricity. The term "current" is, however, most generally reserved for discharge taking place through a conductor.

Electric Glow.—When a conductor, having on it a sharp point, is electrified, it is found that the surface-density is much greater at, or near, the point than elsewhere. The strength of the electric field just near to the point is therefore very much greater than at other places near parts of the surface not pointed. The dielectric strength of air being limited, when the density reaches a certain limit the insulating resistance of the air gives way, and there is an electric current or continuous discharge from the point into the air. The air becomes faintly luminous, and gives rise to a *glow* or point of light, seen on the sharp termination of the conductor when viewed in the dark.

Electric Wind.—The air near the point becomes, therefore, electrified with electrification of the same sign as that on the conductor. If this air could be kept still, the conductor would retain its charge, but owing to the mobility of the air particles, they are repelled and carry their charge with them; other unelectrified air molecules take their place, and, the same effect being repeated, there results a rapid flow of electrified air particles from the point, which is called an *electric wind.*

Electric Brush.—If a blunt point or small ball is placed on a conductor and electrified, an electric field is produced near the blunt point, which is not so strong near the point as in the case of a sharp point raised to the same potential. Under these circumstances a succession of rapid discharges takes place into the air, illuminating it faintly along the lines of force, and giving rise to a hissing sound. From the fan-shaped appearance it is called an *electric brush discharge.*

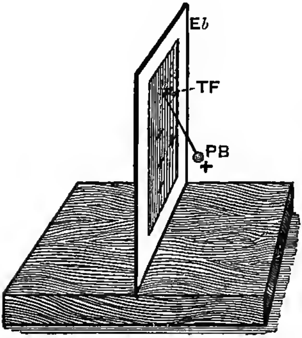


VACUUM TUBE WITH DISCHARGING POLES.

Electric Spark.—When the strength of the electric field between two conductors is considerable all the way between them, as is the case if two spherical conductors are brought near each other oppositely and equally electrified, then when the field is increased beyond a certain limit the discharge takes the form of a spark. Along the path of the discharge the air is rendered highly luminous and incandescent, and the conductors are completely discharged. The path of the spark is often irregular, because in rupturing the dielectric the electric current takes the line of least resistance.

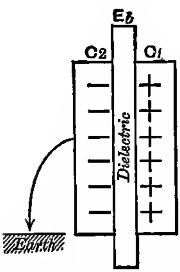
Vacuum Tube.—A glass vessel containing air or other gas which has been rarefied to a pressure at which the discharge ceases to be disruptive, and takes the form of a glow or brush-like discharge through the space, is called a *vacuum tube.*

Condensers and Condensation of Electric Energy.—A condenser consists simply of two conducting surfaces brought *near* together and separated by a dielectric of air, glass, ebonite, resin, paraffin-wax, or other good insulator, whereby the electrical capacity is rendered great. The surfaces are termed the *coatings* of the condenser.



SIMPLE CONDENSER.

The simplest possible condenser that one can conceive of is two insulated metal plates separated by air. The next simplest, and one easier to handle for experimental purposes, is a thin sheet of unglazed ebonite, Eb,* or a pane of varnished glass covered partly on the middle of each side with tinfoil, TF. These two coatings of tinfoil constitute the conducting surfaces, and being eparated by a thin insulator, the three combined form what has been termed a condenser. For the purpose of indicating the potentials of the charges imparted to the coatings you may fix a pith-ball, PB, on each side, attached to the tinfoil by a fine thread, and when demonstrating with the apparatus, it is convenient to set it into a wooden base, as shown by the above figure.



CHARGING A CONDENSER.

EXPERIMENTS XXI.—(1.) *Charging a condenser.*—Holding this condenser by the wooden base, connect one side to earth by placing your finger upon the coating, C_2, whilst you bring the other side, C_1, near to or in contact with the prime conductor of an electrical machine, as shown by the accompanying section, where the coatings have been intentionally drawn thick, in order to admit of indicating the + and – signs. When you work the machine, coating C_1 becomes charged with + electricity, which induces across the ebonite, Eb, an almost equal quantity of – on the inner surface of C_2, and repels + to earth. The – on C_2 hugs and binds the + to the inner surface of C_1, permitting

* Polishing the surface of ebonite deteriorates the insulation resistance. It is best to rub it with a sheet of glass-paper aud to leave it thus. Further, ebonite requires to be rubbed in this way from time to time, owing to oxidation of its surface reducing the insulation, especially if it has been exposed to sunlight.

more + to come from PC. This additional + attracts more − on C_2, which in turn reacts on the newly-deposited +; and so on, until the condenser becomes charged with the utmost quantity that its capacity will receive under the pressure or potential difference generated by the machine; for you remember the formula which we explained to you in the last Lecture, viz., Quantity = capacity × potential difference, or $Q = K \times V$.

If the pressure attained by the machine be very great, then the condenser may be charged until the electricity either sparks right round the edges of the ebonite, over its surface, or through the air from C_1 to C_2, or discharges clean through the ebonite sheet, piercing it with small holes. Suppose, however, that your condenser is suited to the limits of your machine, and that none of these things takes place. Remove it from the prime conductor when it is fully charged, and set it down on the lecture-table. You now observe that the pith-ball is repelled from C_1 by its free + charge, but the other pith-ball attached to C_2 is *not* repelled, since the *entire* − charge on C_2 is held bound on its inner surface by the + charge on C_1. The condenser is now in an insulated condition, and if the insulation of the ebonite dielectric be very good, it will retain the charges for a day or more.

(2.) **Discharging a Condenser by Removing the Free Charges.**—Touch the − side, C_2, say, with your left hand. You get no shock whatever, for there is no *free* − charge on it; it is all bound hard and fast to that face of the ebonite by the + on C_1. Remove the hand and touch the + side, C_1; you get a very small spark and shock, thus showing that there is a small quantity of *free* + there, and at the same instant the pith-ball on C_2 diverges, whilst the pith-ball on C_1 falls perpendicular. Now touch the − side, C_2, and this time you get a small spark and shock, indicating that the withdrawal of the free + on C_1 had set free a small quantity on C_2. Go on touching alternately each side until you completely discharge the condenser. From this experiment you learn that there is not exactly the same quantity of electricity stored on each side of a condenser that has been charged with one side to earth, for a small quantity of the electricity on the charging side is free to act inductively on surrounding earth-connected bodies, and is therefore not bound by the immediately opposing charge on the condenser. We may illustrate this by an arithmetical example. Suppose that the total charge on the + side was equal to 42 units, and on the − side to 36 units of quantity, thus leaving a difference of 6 units. Touch the + side and the 42 units will be reduced, say, to 30 units, or 6 less than the − side. Now touch the − side, and suppose you discharge 11 units, leaving 25, or 5 less

than on the + side, and so on in the proportions indicated by the following set of figures, showing the free charges on each side before each discharge of the other side:—

+ side C_1 *free* charges left	12,	10,	8,	6,	4,	2.	= Total 42 units.
– side C_2 *free* charges left 0,	11,	9,	7,	5,	3,	1.	= Total 36 units.

Short-Circuiting or Discharging a Condenser at Once.—Charge the condenser again in precisely the same way as before, and set it on the table. Place your left hand on the – side, C_2, and bring round the right hand gradually towards the + side, C_1. When within a short distance of it you suddenly see a brilliant spark and feel a severe shock. You have nearly short-circuited the condenser coatings, but *not quite;* for if you have not touched C_1, and you remove your right hand for a little time and again bring it forward as before, you find upon getting much closer than the previous time that you do get a second spark and shock. This second discharge is, however, much less brilliant and severe than the first one, but still sufficient to show you that a small quantity remained on C_1 after the first discharge. This second quantity has been termed the *residual* charge, and the phenomenon itself is called the electric absorption of the dielectric. Some dielectrics absorb or permit the electricity to soak into them more slowly, yet retain it more firmly than others, and consequently they give a greater number of residual charges. To use a homely simile, you know that some finely-pored sponges absorb water more slowly, yet retain it more firmly, than those with large pores, so that several squeezes are required before the whole of the water is discharged from them.

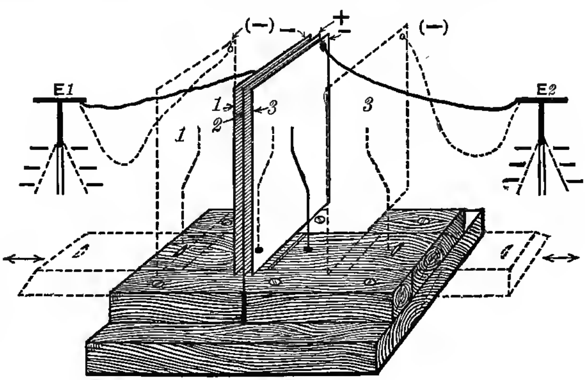
Another thing that you might learn from a series of experiments of the kind just performed is this, that if you took different dielectrics of the same thickness as the ebonite one, and covered them with tinfoil coatings of the same shape and size, you would get different quantities of electricity stored when they were respectively fully charged to the same potential. In other words, you would find out that different dielectrics have different inductive capacities. Air is taken as the standard by which the relative inductive capacities of other substances are gauged; hence we have the following definition:—

DEFINITION—**Specific Inductive Capacity.**—*The ratio of the electrical capacity of a condenser, when made with any particular dielectric, to its capacity, if the dielectric be replaced by air, is called the* SPECIFIC INDUCTIVE CAPACITY *of that dielectric.*

The greater the inductive capacity, the greater will be the quantity that will accumulate on a condenser of specified dimensions.

The Potential of a Conductor Depends Partly on its Position.—This important statement may be very easily proved by aid of a condenser with movable coatings, such as we have illustrated by the accompanying figure, where 1, 2, and 3 represent three insulated metal plates with rounded edges and corners, not shown. Plate 2 is fixed, whilst 1 and 3 can be moved towards or from 2 at pleasure by simply pushing or pulling their respective dove-tailed wooden bases.

Experiment XXII.—Connect plates 1 and 3 to electroscopes, as shown by the figure. Charge 2 positively when both the other plates are near it, until the leaves show a slight divergence; earth 1 and 3, and then free them; withdraw them to the dotted-line positions, and you immediately find that the leaves diverge



Condenser with Two Movable Coatings.

much farther with − than when at the full-line position. Bring them to their former positions again, and the leaves collapse to the same extent as before.

Consider these results by aid of the formulæ we gave you in the last Lecture—

Viz., $$K = \frac{Q}{V} \text{ or } V = \frac{Q}{K}.$$

Now Q, the quantity, remains constant, but K, the capacity, diminishes enormously the farther the plates 1 and 3 are removed from 2; consequently the potential V increases as shown by the increased divergence of the leaves of the electroscopes. This shows that if any insulated electrified body connected with an electroscope be moved from a position near to the walls of a room into the middle of the room, or far from all earthed bodies,

the potential of the body will rise, as evidenced by the increased divergence of the leaves.

Practical Uses of Condensers.—Every aerial telegraph line constitutes a condenser of low capacity; for you have the wire as one coating; the earth, neighbouring trees, and houses as the other coating; and the intervening air as the dielectric or separating medium. A submarine cable, if long, becomes a condenser of great capacity, for you have the copper conductor as one coating; the water or iron wire sheathing as the other coating; separated by a thin layer of gutta-percha or india-rubber, substances of considerable specific inductive capacity. A telegraphic signal or momentary charge of electricity entering an Atlantic cable at Ireland for America is therefore affected not only by the resistance of the copper conductor, but by the electrostatic charge, which causes a lingering of the electricity, and hence a drawing or lengthening out of the received signal. Consequently, it takes a much longer time for a signal to pass through a submarine cable than in the case of a land line of the same length and resistance, due to the greater capacity of the former, and the signal is also weaker on its arrival at the farther end. It is owing to this that instruments of the greatest sensitiveness, capable of recording weak and prolonged signals, have to be used for submarine telegraph work, such as Sir William Thomson's mirror galvanometer (see Part II.) and his syphon recorder (also already referred to). In order to increase the sharpness of the signals, condensers, consisting of many sheets of tinfoil separated by thin layers of paraffin-waxed paper, are placed at each end of the cable. These condensers are so arranged that they discharge themselves quickly, and thus sharpen into a definable indication what would otherwise be unreadable. Condensers are also used for duplex and quadruplex working along with subdivided resistances, so as to imitate as nearly as possible the exact conditions of the cable or land line, and by an arrangement of balancing the flow of currents to and from the opposite ends of the line, telegraphists are enabled to communicate both ways at one and the same time.*

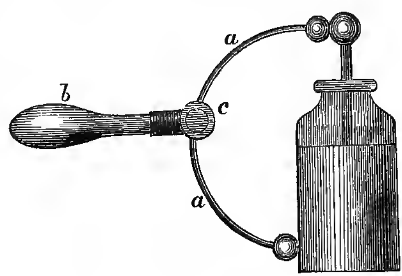
The Leyden Jar.—A Leyden jar is simply a condenser with a glass bottle for the dielectric, and usually a coating of tinfoil or gold-leaf inside and outside of the bottom, and so far up the sides as illustrated by the following figures. What we have said and proved in regard to the simple condenser is equally applicable to the Leyden jar under similar circumstances, hence

* See pp. 310 to 315 of the 6th edition of Munro and Jamieson's "Pocket-Book of Electrical Rules and Tables;" also see pp. 113, 114, for joining-up condensers in series and in parallel.

there is no need for repeating the whole of the statements and experiments.

This form of condenser takes its name from a town called Leyden, near the Hague, in Holland, where, in the year 1746, Cuneus, a pupil of Muschenbroeck, an eminent philosopher, wished to electrify water. He employed a wide-mouthed flask held in *one hand*, while the collecting chain from a frictional machine (of the old sulphur-sphere type mentioned in last Lecture) dipped into the water in the flask. After charging the water for some time, he wished to disconnect the chain, and on touching it with his *other hand*, he received a shock which astonished him, for it made him let go the flask, and he took a couple of days to recover his equilibrium.* He communicated his accidental discovery to Réaumur (the inventor of the Reaumur thermometer), who communicated it to others, and these eagerly repeated it, causing great excitement for a time amongst the scientific savants of Europe and America.

How to Charge and Discharge a Leyden Jar.—EXPERIMENTS XXIII.—(1.) *To charge the inner coating with + electricity.*—Hold the jar by the outer coating with one hand, bringing the outstanding knob connected to the inner coating *into contact* with the + or prime conductor of a working electrical machine, if you wish to charge the jar to the *full* potential that the machine can produce. If you hold the knob some distance away from the prime conductor and permit sparks to pass between them, the potential will naturally fall in overcoming the resistance, and the energy of the charge that enters the jar will just be diminished by the corresponding value of the heat developed in creating the spark. Besides this, in the first case, you prevent the possibility of your getting a shock, for the electricity streams into the jar.



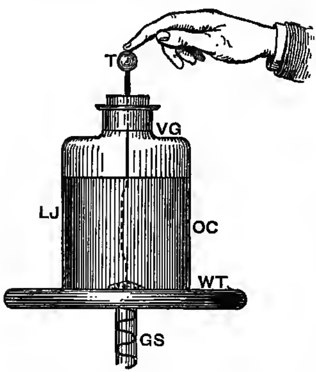
DISCHARGING TONGS AND LEYDEN JAR.

* Probably a rapid series of discharges from Leyden jar batteries (see last figure in this Lecture) would prove a more effective method of *electrocution* than that attempted on Kemmler at the Auburn Prison, New York, on August 6th, 1890, when he revived after eighteen seconds application of an 1800-volt current from a dynamo machine. It is, however, to be hoped that this, the first, is also the last attempt to apply electricity to such a horrible purpose.

(2.) *To charge the outer coating with + electricity.*—Take hold of the knob of the jar with the hand, and bring the outer coating into contact with the prime conductor. Or you may earth the prime conductor and free the earth-conductor, bringing the knob into contact with the latter, as explained in the last Lecture.

(3.) *If both the prime and earth conductors are free.*—Place the jar on an insulating stool and connect the knob to the prime or the earth conductor by a wire, just as you desire to get + or − electricity on the inside coating, and the outside coating to the other pole or conductor.

(4.) *To discharge a jar rapidly.*—Place the jar on the table. Take hold of the insulating handle, *b*, of the discharging tongs; bring the one end of the metal tongs, *a a*, into contact with the outer coating and gradually the other end near to the knob. A violent spark and loud report will take place if the jar is of large capacity and well filled. Finally, hold the tongs for a short time in the position indicated by the above figure, in order to clear out all the residual charge.



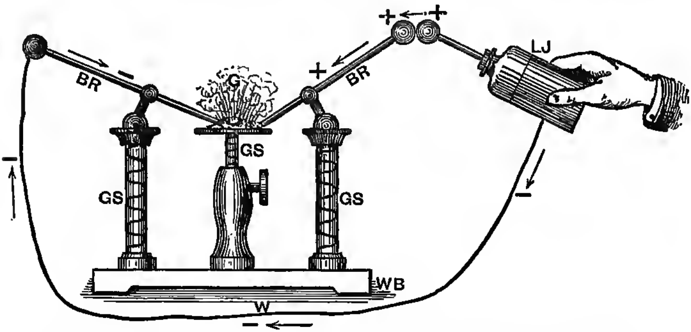
Discharging the Free Charge of an Insulated Leyden Jar.

LJ represents Leyden jar.
T „ Top (*connected to inner coating by a chain or wire*).
VG „ Varnished glass (*varnished inside and outside*).
OC „ Outer coating (*made of tinfoil*).
WT „ Wooden table.
GS „ Glass support.

(5.) *To discharge a jar slowly by alternately abstracting the free charges.*—Place the Leyden jar on an insulated wooden table. Touch the top, T, and discharge the small quantity of free electricity on the inside coating, then touch the outer coating; and so on alternately, until the jar is completely discharged, as explained in the case of a simple condenser in Experiments XXI., Case 2. You may apply a similar arithmetical example to this case.

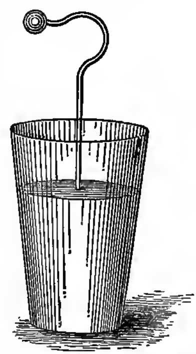
(6.) *To discharge a jar through combustible material.*—The brilliant spark produced on the discharge of a Leyden jar by the discharging tongs is a sign of the intensity of the heat developed by the combination of the + and − electricity; for it shows that the air has been rendered incandescent. If a Leyden jar be held in the hand, or if the outer coating be con-

nected to a gas-pipe by a wire, and the knob be brought near to the gas escaping from a burner, the spark, as it passes from the knob to the metal part of the burner, will set fire to the gas. The heating effect of discharge is considerably increased by introducing a moderate resistance to the path of the discharge. In



SETTING FIRE TO GUNPOWDER PLACED ON A UNIVERSAL DISCHARGER.

order to illustrate this effect, take a "universal discharger," as shown by the accompanying figure.* Fix the points of BR about $\frac{1}{4}$ inch apart, and above the table. Pour some dry gunpowder, G, between them, so as to bridge them over. Discharge the Leyden jar (as indicated by the figure), using a thick copper wire between the left-hand discharge rod, BR, and the outer coating; the powder will simply be scattered without ignition. Introduce a few inches of wet string between this wire and BR, and again discharge the jar. This time the powder will be ignited. Or if you leave the wire, W, as before, and simply connect the two brass rods, BR, between the universal ball-socket joints with a wet string, the powder will be set on fire. We shall have occasion to return to this effect in our Advanced Course, with a view to explaining it by the aid of Dr. Lodge's recent discoveries.



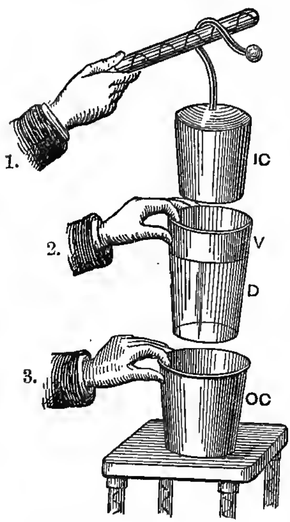
LEYDEN JAR WITH REMOVABLE COATINGS.

Seat of the Charges in a Condenser or Leyden Jar.—Benjamin

* The advantage of using this apparatus lies in the adjustability of all the parts, whereby the little operating table may be raised or lowered, and the discharging brass rods, BR, placed at any convenient distance apart, and position with respect to the substance to be operated upon.

Franklin discovered that the seat of the charges is on the surface of the dielectric, and not on the metallic coatings. This may be demonstrated to a class in a very simple manner.

EXPERIMENT XXIV.—Take a Leyden jar of the form shown by the previous figure. Charge it from the electrical machine. Set it on an insulating stool. Remove the inner coating, IC, by an *insulating* rod, as indicated by the first figure, and hand it to a student. He will get no shock on handling it. Remove the dielectric, D (glass tumbler), by the varnished part, V, as in the second figure. Hand it to another student, seeing that he grasps it by the lip *only*. He will feel nothing. Lastly, get a third student to take hold of the outer coating, OC, and he notices nothing. Now get them to replace the things on the insulating stool in the reverse order, but in the same way as before removal. Then ask any one to touch the outside and inside coatings simultaneously, when he will receive a "stunning" shock, quite as strong as if the jar had been discharged without having been separated and then united.



DISCONNECTING LEYDEN JAR WITH REMOVABLE COATINGS.

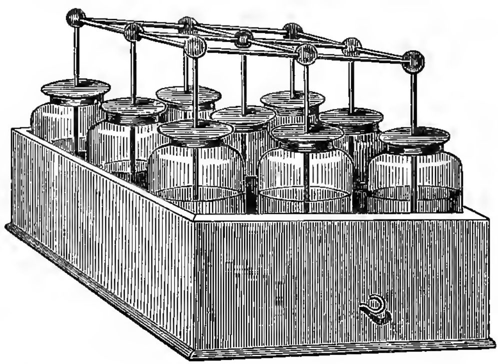
This clearly proves that when the coatings are removed the charges reside on the dielectric, but whether this be the case when the coatings are in position we cannot say. The coatings probably only touch the dielectric in a few places, and the binding attraction which the + and − charges have for each other keeps them from being removed during the removal of the coatings.

Joining-up Leyden Jars to Form a Battery.—(1.) *In parallel for quantity.*—Connect all the inner coatings together by conducting wires, and all the outer coatings by placing the whole of the jars in a tinfoil-lined case, as shown by the accompanying figure.

If there be n jars of equal capacity, K, in the battery, then the capacity of the whole will be n K. If the potential of the charge be V, then the total quantity $= n\text{VK}$.

(2.) *In series for high potential.*—Charge each of the jars separately in the usual way. Place each jar as it is charged on

an insulating plate of varnished glass supported by varnished glass legs. Connect the knob of 1 to the outer coating of 2 by the insulating tongs, the knob of 2 to the outer coating of 3 in the same way; and so on for the n jars, the knob of the nth jar being free. Let K be the capacity of each jar and V the potential of each before connecting up. When 1 and 2 are connected, they have a combined potential difference of 2V; when 1, 2 and 3 are connected, the potential difference is 3V, and so on; so that the knob of the nth jar has a potential of nV over that of the outer coating of the first jar. The maximum distance that you now require to bring the connecting wires or discharging tongs between the extreme coatings before a spark will take place, is therefore far greater than in the former case, when the poten-



THE LEYDEN BATTERY OR JARS JOINED UP FOR QUANTITY.

tial was V; but the quantity of the charge is evidently *only* equal to that of one jar, or $Q = KV$.

This plan we have just been describing is not the same as the old useless method of joining up for "cascade," which we have not time to discuss at present.

In dealing with the several questions found at the end of this Lecture, we would again remind you that a Leyden jar is only a condenser, and that you will have to apply our remarks on condensers to the solution of these questions.

Final Remarks.—When we commence our Advanced Series of Lectures, we will reverse the order of treatment, and finish what we have to say about frictional electricity, because it will be fresh in your memory, and a full understanding of the absolute units, potential, quantity, capacity &c., as well as of the energy spent in developing heat during discharge, is necessary in order to rave

the way for questions on electro-kinetics, &c. There is not the same excuse for avoiding the November fogs, because in the Advanced Course the treatment is of necessity more mathematical and quantitative than relating and demonstrating striking experiments. The interest will, however, be kept up by descriptions of the practical applications of electro-statics, which we have been obliged to avoid, owing to their complexity and to want of space.

Lecture XXVIII.—Questions.

1. Describe an experiment to illustrate the action of points in discharging Winter's plate frictional machine.

2. A thunder-cloud charged positively comes over a pointed lightning-conductor. The cloud generally loses its charge of electricity by the action of the conductor. How is this accomplished? (S. and A. Exam., 1877.)

3. Describe an experiment with Winter's machine to illustrate the action of flame in discharging it; and, reasoning from the results, show how a fire on an elevated position will discharge atmospheric electricity or lightning.

4. Define, in your own words, disruptive discharge, continuous discharge, electric glow, brush, and spark.

5. Sparks pass between the prime conductor of an electrical machine and a metal knob connected with the earth, held near to it. Describe the changes, if any, in the phenomena observed, as the knob is gradually moved away from the prime conductor. (S. and A. Exam., 1889.)

6. An insulated electrified ball is connected with an electroscope by a long wire, and the leaves diverge. The ball is then moved to another position, its connection with the electroscope being maintained by means of the wire. How would you decide whether the ball has undergone any change of potential? Give reasons for your answer. (S. and A. Exam., 1890.)

7. Two equal insulated uncharged spheres, B and C, are placed on opposite sides of, and at equal distances from, a charged sphere, A. What is the electrical state of B and of C, and what will happen if the part of B nearest to A is connected by a fine wire with the part of C farthest from A? (S. and A. Exam., 1890.)

8. Describe an experiment which shall illustrate the action of the electrical condenser. (S. and A. Exam., 1878.)

9. Sketch a Leyden jar in section, describe its construction, and explain fully what occurs during the charging and the discharging of the jar.

10. You are required to make a small Leyden jar: how will you proceed? You are required to charge the jar when made: how will you do it? You are required to explain fully what occurs during the charging and discharging of your Leyden jar. (S. and A. Exam., 1877.)

11. On touching the knob of a charged Leyden jar standing on the floor or on a common table, you get an electric shock; but if either you or the jar stand on a dry cake of resin, you do not get a shock on touching the knob. Explain this. (S. and A. Exam., 1885.)

12. The inner coating of a Leyden jar is connected by a wire with the prime conductor of an electrical machine and also with a gold-leaf electroscope. If the jar rests upon a sheet of glass, a quarter of a turn of the machine produces a large divergence of the leaves of the electroscope. If the glass be removed, ten turns of the handle are required to produce the same deflection. Explain this. (S. and A. Exam., 1888.)

13. One person holds a charged Leyden jar in his hand by its outer coating, and another holds similarly an uncharged jar. What happens when the knobs of the two jars are brought together? (S. and A. Exam., 1880.)

14. Describe fully how you could charge a Leyden jar from the positive conductor of an electrical machine, so as to get at will either a positive or a negative charge on the inner coating. (S. and A. Exam., 1879.)

15. You have an electrical machine standing on a table with a glass top, and you have no means of connecting it electrically with the earth. What would you do in order to charge a Leyden jar by the machine? (S. and A. Exam., 1884.)

16. A Leyden jar is hung up in the air by a silk string; the knob of the jar is connected with an electric machine, and its outer coating is connected by a wire with a large gas-pipe. What occurs in this outer wire when the machine is worked, and why does it occur? What would happen supposing the string to be ordinary twine? Let your answer be as clear and as complete as possible. (S. and A. Exam., 1871.)

17. An electrified metal ball is introduced into a dry glass tube closed at one end, and then, the tube being held in the hand, is brought near to the cap of an electroscope. What will the effect on the electroscope be if the exterior of the tube (1) is, (2) is not, covered with tinfoil. (S. and A. Exam., 1889.)

18. You charge a Leyden jar by holding its outer coating in the hand and bringing the knob to the prime conductor of an electrical machine. If you wished to charge the jar to as high a potential as possible, would you hold the knob in contact with the prime conductor, or keep them a small distance apart? Give reasons for your answer. (S. and A. Exam., 1889.)

19. A Leyden jar was twice charged and discharged. The first time the knob was held a quarter of an inch from the prime conductor of the electric machine; the second time the knob was in contact with the prime conductor. Both times the machine was worked for the same interval. In which case will the discharge spark be the brighter? Give reasons. (S. and A. Exam., 1890.)

20. One end of a guttapercha-covered copper wire is connected with an electrical machine, and the other dips into a non-conducting liquid. When the machine is worked the liquid is agitated. Explain this. (S. and A. Exam., 1891.)

21. Describe an experiment to prove that two points may have the same potential, though one is charged with positive electricity, and the other is either uncharged or charged with negative electricity. (S. and A. Exam., 1891.)

APPENDIX TO PART III.

PRACTICAL NOTES ON MAKING EXPERIMENTAL APPARATUS FOR STUDYING FRICTIONAL ELECTRICITY.*

To Make a Glass Tube Electrogen.—(See figs., pp. 202, 212, 222.)—(1.) Buy a glass tube (of the best flint glass, free from scratches or blemish), about 2 feet long and $1\frac{1}{8}$ inch outside diameter.

(2.) Attach a clean muslin cloth to a piece of whipcord. Saturate the cloth with spirits of wine or wood-naphtha, and pull the cloth through the inside of the tube several times until the tube is *perfectly clean.* The spirits of wine or naphtha will soon evaporate.

(3.) Hold one end in the blowpipe or Bunsen flame until the glass becomes plastic. Turn it round and round, holding it with the end in the flame downwards, at an angle of 45 or more degrees, until the end becomes sealed. Then blow gently into the open end until you form a neat smooth round end. Heat the tube slightly from the closed end towards the open one, so as to expel the moisture which got inside from the breath, and try to close the open end with the flame as you did the other one. Should you fail in doing this, cork it up and cover the cork end with shellac varnish or use an india-rubber cork.

(4.) Clean the outside thoroughly with spirits of wine or wood-naphtha.

To Make a Balanced Glass Tube.—(See figure, page 207.)

(1.) Buy a flint glass tube about 18 inches long and $\frac{3}{4}$ inch outside diameter.

(2.) Clean it and close one end in the manner described above.

(3.) Balance it on a knife-edge, and mark the balancing spot with ink.

(4.) Hold the tube level (without turning it) in the blowpipe or Bunsen flame until a small spot slightly nearer the point than where the balancing mark is, becomes soft. Then quickly suck the air out of the tube at the open end, when a $\cap$ will be formed inside the tube. Heat this part gently until it becomes soft again, and quickly force a needle-point into the $\cap$ until it becomes a $\wedge$ centre.

(5.) Try the effect of balancing the tube, and adjust the balance perfectly by closing the other end in the blowpipe (after expelling the moisture by heating the tube gently from the closed towards the open end).

(6.) Finally, clean the outside with a cloth and spirits of wine or clean water.

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* Read the Preliminary Note to Appendix, Part I.

To Make an Ebonite Rod.—(1.) Buy a round rod of the best insulating ebonite, about two feet long and one inch in diameter.

(2.) File it perfectly smooth, and round the ends neatly.

(3.) Glass-paper it all over, taking care not to touch it with oily or dirty hands.

(4.) Do not attempt to polish the rod, since it acts better as a generator and insulates far better if left as described.

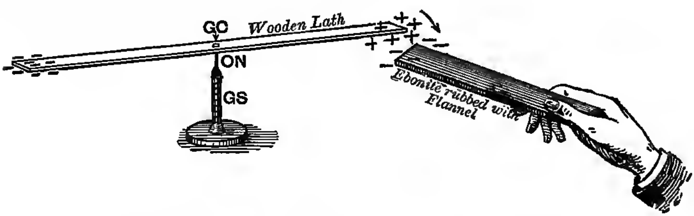
To Make a Balanced Ebonite Rod.—(1.) Buy a piece of the best insulating ebonite, about 18 inches long, ½ inch thick, and ¾ inch broad.

(2.) File it straight, round all the edges and ends, and glass-paper it all over as described above.

(3.) Balance it carefully on the broad side, and mark the spot where it balances with a sharp point.

(4.) Make a glass ⋀ centre, as described at p. 73 (5).

(5.) Bore a tapered hole through the balancing point, and fix the ⋀ centre into the hole with shellac, so that the point of the centre barely appears on the surface of the other side of the rod. When the shellac has become hard, file off the base of the ⋀ centre flush with the rod.



BALANCED LATH, INSULATING STAND, AND EBONITE ROD.

(6.) Clean out the ⋀ centre with a pin, cotton, and spirits of wine, and try how it balances. You may have to file and glass-paper the rod a little at one end before you obtain a perfectly true balance, but a little time spent in doing so is well repaid by the after satisfaction of its working well.

To Make a Balanced Lath.—(1.) Buy a strip of the best straight-grained yellow pine, free from knots, 6 feet long, 2 inches broad, and ¼ inch thick.

(2.) Plane it straight and smooth, tapering it down from $\frac{3}{16}$ inch at the middle to *less* than ⅛ inch thick towards each end, keeping the breadth uniform.

(3.) Adjust a ⋀ glass centre at the centre of gravity by shellac (see Part I., p. 73 (5)), and balance it perfectly.

To Make an Insulating Stand for the Balanced Rods and Lath.—(1.) Buy a piece of yellow pine or mahogany, 5″ × 5″ × ¾″, and plane it up square (as directed in Part II., pp. 192, 193), for a base to the stand. Glass paper and varnish the stand.

(2.) Buy a tube of the best flint glass, without scratch or blemish, about 8 inches long, and ⅝ inch outside diameter.

(3.) Clean the inside (as directed in the case of the larger glass tube), and close one end in the blowpipe flame, or seal it with melted shellac flake.

(4.) Round the edges of the other end of the tube in a Bunsen flame.

(5.) Fix a darning-needle firmly and fairly into the open end by melted shellac, tapering the lac to a neat cone round the pin by heating it gently in a Bunsen flame, and pressing it between the moistened forefinger and thumb.

(6.) Bore a hole in the centre of the wooden base to fit the tube *tight*, and so that the tube stands perfectly plumb when pushed into the hole.

(7.) Remove the tube from the base and clean it with spirits of wine. Holding the tube by the needle, warm it gently over a Bunsen flame until it is a little above blood-heat, then varnish it by drawing the varnish brush *once* from end to end over each part of the surface.

To Make Shellac Varnish.—Put 1 ounce shellac into a wide-mouthed 8-ounce phial containing 5 ounces of rectified naphtha or wood spirit. Cork and stand in a warm place until the gum is dissolved. Shake frequently and filter, adding more naphtha to assist the filtering, and changing the filter from time to time.

Or, just cover the lac with methylated spirit and leave it for twenty-four hours with an occasional shaking. The clear solution is poured off and the undissolved lac treated with a little more spirit.

To Make Insulated Conductors for Testing Distribution of Charges.—(1.) Buy pieces of well-seasoned yellow pine nearly of the shape and size required, leaving a sufficient margin for turning them down to the exact dimensions.

(2.) Turn the pieces of wood perfectly smooth to the shape required in lathe. Also turn a wooden base. If you have not got a lathe, buy them turned. For a sphere such as shown by the accompanying illustration, you will find that from 4 to 6 inches diameter will be a most convenient size, with a base of 5 to 7 inches diameter by 1 to $1\frac{1}{4}$ inch thick.

(3.) Buy a flint-glass rod from $\frac{5}{8}$ to $\frac{3}{4}$ inch diameter and 10 to 12 inches long. Clean and varnish this rod in the manner directed above for the insulating stand. Do not finger it, except at the ends, after varnishing, for fear of reducing the insulation.

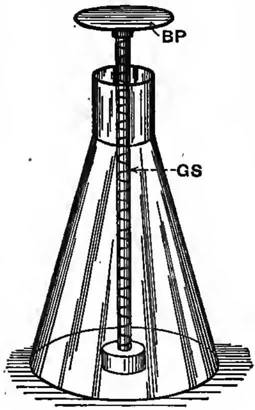
(4.) Bore a hole radially to the centre of the sphere or straight towards the centre of gravity of the otherwise shaped bodies, so as to fit the glass rod easily. Bore a hole through the centre of the base to fit the other end of the rod *tightly*.

(5.) Cover the whole surface of the wooden sphere or other shaped conductors evenly and smoothly with gold-leaf or gilt paper, leaving *no* outstanding lirks or points. In the case of wishing to cover the wood with gold-leaf, you had better consult a gilder or get him to cover it for you.

Such a form of conductor is cheap, light, and serves the desired purpose equally as well as a solid or hollow metal conductor.

The following form of insulating stand is strongly recommended by Professor Ayrton. It may be made by a student in the following manner:—

(1.) Procure a deep bottle with a broad or conical shaped base and not too wide a neck, such as a lozenge bottle.



(2.) Obtain a rod of the best flint glass, with which to make the glass stem, GS, without scratch or blemish, of a length to reach the bottom of the bottle and to extend beyond the neck 2 to 3 inches.

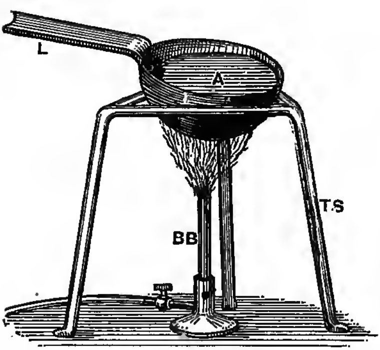
(3.) Fit a broad *lead* weight tightly to one end of this glass rod, and of such a diameter that it can just pass through the neck of the bottle.

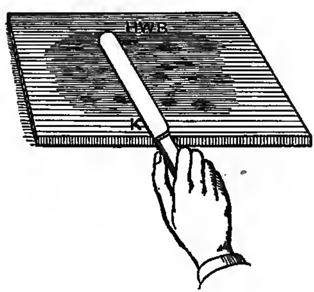
(4.) Fit easily a brass plate, BP (or any other shape of body, such as the sphere, oblong, and pear-shaped bodies mentioned in Lecture XXVI.) to the top end of the glass rod. The differently-shaped bodies may replace each other as required; while the brass plate, or an insulating ebonite plate, will serve as a small table upon which you can place any other charged body.

(5.) Pour a little strong pure sulphuric acid into the bottle, but not sufficient to reach the top of the conical base. Clean the glass stem GS and place it in the bottle as shown. The sulphuric acid absorbs moisture from the air, and keeps the stem dry. The stem may be taken out and cleaned at any time.

To Make Amalgam for Glass Rubbers.—(1.) Procure the loan of a plumber's ladle, L. Place it on a tripod stand, TS, above a lighted Bunsen burner, BB.

(2.) Melt in this ladle 1 oz. of tin. Add gradually 1 oz. of zinc, and thoroughly mix them with an iron rod stirrer.





(3.) Add gradually 2 oz. of mercury, and keep stirring all the time.

(4.) Allow the mixture to cool until it becomes thick.

(5.) Pour out as much as you require for immediate use on to a hot wooden

board, HWB, and mix it thoroughly with a little washed and dried lard by means of a flexible knife, K. Put the rest into a stoppered glass bottle.

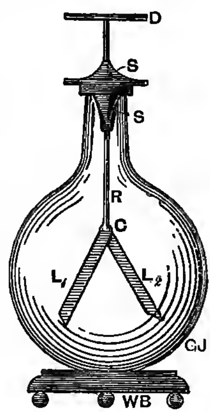
(6.) Spread this mixture thinly and evenly over the silk or leather rubbers.

To Make a Gold-Leaf Electroscope.—(1.) Procure a neat glass jar, GJ, like that shown in the accompanying figure.

(2.) Clean the inside of the jar—or Florence flask*—*thoroughly*, by washing it out with soapy water, and then with clean warm water. Heat the jar gently from the bottom towards the neck, by turning it round and round over a Bunsen or spirit-lamp flame, until the whole of the moisture has been expelled; then cork it up to prevent dust getting inside.

(3.) Turn a neat wooden base, WB, to fit the round of the bottom, and fix it by glue or shellac to the vessel.

(4.) Procure a brass rod, R, about $\frac{1}{8}$ to $\frac{1}{4}$ inch diameter, and of sufficient length to project some 3 inches from the top of the neck when the lower end is lowered to the centre of the globe part of the flask. File the latter end of this wire round, and cut a central saw drift up it for about $\frac{1}{2}$ inch from the end.



(5.) File a piece of sheet brass or zinc into a ⌂-shaped clip, C, with well-rounded edges and corners, so as to fit tightly into the saw-drift in the rod, keeping the flat end about 1 inch broad, and placing it downwards. Screw the upper end of the wire or turn it down to a tapered rounded end.

(6.) Turn a disc, D, about 1 to 2 inches in diameter (according to the size of the electroscope), with neatly-rounded edge, from a piece of brass, say $\frac{1}{8}$ to $\frac{1}{4}$ inch thick. Bore and screw a hole to fit the end of the rod, R, if it is screwed; or bore it with a nice easy taper to fit the taper on the rod, if this plan has been adopted. The advantage of fixing the plate on a taper is, that other forms of discs or caps may be fitted on to the rod, R, at pleasure; for example, a ball or a point. Bore a hole near the edge of the cap, $\frac{1}{16}$ or so in diameter, to facilitate the introduction of a copper wire (No. 16 standard wire gauge), or a large darning-needle, or a match.

(7.) Turn a wooden stopper to fit the neck of the flask, and bore a hole in the centre of it about $\frac{1}{2}$ inch to $\frac{3}{4}$ inch diameter, according to the diameter of the rod R.

(8.) Heat the wire slightly in a Bunsen burner flame at the place where the shellac, S, has to be fixed. Neatly mould round the rod a double cone of solid shellac, S (as shown by the figure), and then, by gently melting the outside surface of the lac, fix it fair and square into the cork. Try if the rod R now hangs centrally in the flask when the cork is introduced into the neck of the vessel. Scrape both shellac cones with a sharp knife or piece of glass.

(9.) Clean the outside of the flask thoroughly with hot water or spirits of wine.

(10.) Procure gold-leaf. Remove the several parts into a still quiet room or corner. Cut the gold-leaf neatly to the breadth of the cap, C, by placing it on a clean chamois leather pad, pressing it gently, and sawing it with a

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* If it is required for lecture-room experiments, the flask should be about 18 inches high, and 12 inches diameter on the globe part.

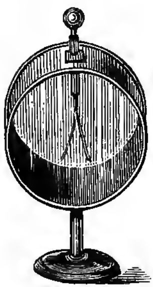
perfectly straight-edged *clean* knife. If Dutch metal be used, it may be cut between paper with long sharp scissors. If the electroscope is of the large lecture-room form, you may have to gum two lengths together for each leaf (say 6 inches long by $1\frac{1}{4}$ inches broad), by a very weak solution of gum. By means of a long thin knife and a little gentle skilful blowing upon the leaves, smooth them out straight and flat on a sheet of white paper. Gum both sides of the clip, C, with the very weak gum solution and lay it down even, fair, and square on the end of the gold leaves in turn. Lift the disc, D, and note that the leaves hang fair with the centre line of the rod R.

(11.) Varnish the inside top-edge of the neck of the flask with shell-lac varnish, taking care that none of the varnish trickles down the neck; or, varnish the stopper and introduce the leaves into the flask.

(12.) Test the electroscope by means of the excited glass and ebonite rods, and see that the leaves diverge equally and well.

To Make a Student's Small Laboratory Electroscope.—(1.) Procure a short thin cylinder of brass or tinned sheet iron, such as can easily be made from a potted preserved meat tin can; or an octagonal tin tea-caddy will do very well.

(2.) Fit a stand to the short cylinder, as shown by the accompanying figure.



(3.) Bore a hole in the centre of the upper side of the metal cylinder, sufficiently large to admit of the introduction of the gold-leaves.

(4.) Cut two circular pieces of glass with a diamond point and fit one of them into its place with putty or shellac.

(5.) Fit a ball or disc as a top to the rod, as well as a clip for the leaves, to the other end. Turn a stopper to fit the hole in the top of the cylinder. Fix the double cone of shellac to the rod and the stopper, as explained in the previous case.

(6.) Cut the gold-leaves (Dutch metal may do for junior students). Fix them to the clips, and introduce them through the hole in the top of the cylinder. Fix the stopper as explained for the previous electroscope.

(7.) Fit on the front glass, and test the electroscope.

(8.) Paste a curved narrow scale (drawn on transparent tracing-paper, with zero at the centre, and divided into degrees), on the front glass, at, or just below, the extreme radius of the leaves. This scale will serve as a means of detecting roughly the potential differences and densities of different charges.

To Make a Proof-Plane.—(1.) Procure a flint-glass rod, about 15 inches long, and $\frac{5}{16}$ inch diameter.

(2.) Heat one end of it in a blowpipe or Bunsen flame until it is quite soft.

Then instantly squeeze it in a vice until it becomes flattened. Heat it again, and bend it round to an angle, as shown by the above left-hand figure.

(3.) Turn or file a disc of zinc or brass, about 2 inches in diameter, and $\frac{1}{16}$ inch thick with rounded edges. (See first and second figure above.)

(4.) Fix the glass rod to the disc by shellac.

(5.) Clean the glass rod thoroughly, and shellac it in the manner stated for the insulating support to the wooden lath.

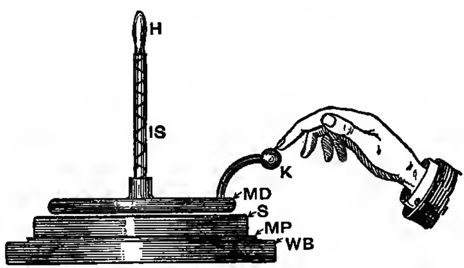
The other forms of proof-planes illustrated may be made by simply turning a piece of zinc or brass to form a plate or sphere, with a socket to receive the insulating glass handle, remembering that no sharp edges are to be left on them. A circular disc of cardboard or vulcanised fibre, covered with gilt paper, and carefully smoothed, will do instead of the metal disc.

To Make an Electrophorus.—(1.) Turn a wooden base, WB, to about 8 inches diameter.

(2.) In order to form the metal plate, MP, it will be sufficient to glue centrally to the upper surface of WB a circular sheet of tinfoil, about 7 inches diameter, and with three radial strips of tinfoil extending over the edge of WB to the under side.

(3.) Melt a quantity of rod sulphur in an ordinary flat-bottomed circular soup plate, allowing the sulphur to cool slowly. When cool, turn it out, and glue it centrally to the metal plate, MP, or wooden base, WB.

(4.) Turn a wooden disc to the size of the circular top of the sulphur disc.



(5.) Cover this with gilt paper, taking care to leave no lirks or outstanding points.

(6.) Glue on a nipple to the centre of this disc, with a hole in it to receive a shellac-varnished rod for a handle.

(7.) Flip the sulphur disc with a cat's skin, and test the efficiency of the whole apparatus, as described in Lecture XXV., p. 242.

Professor Guthrie gives the following recipe for an electrophorus, which is more expensive on account of the price of the wax and shellac used for the insulating plate.

"To make the cake for an electrophorus, one part by weight of wax may be melted in a pan, and five parts of shellac gradually added, with increased heat. Or, five parts of shellac, five of gum mastic, two of Venetian turpentine, and one of marine glue. If, after casting, bubbles appear on the surface, they may be brushed over with the flame of an air-gas burner, which breaks them."

The surface of the sulphur or compound shellac cake may be made sufficiently flat by scraping it carefully with a carpenter's chisel, so as to fit the under side of the metal disc, MD.

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